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1 April 1941

TEST OF UNDERWATER RECEPTION
OF LOW FREQUENCY RADIO SIGNALS

by F. C. Isely

Report No. R-1717

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26 Sept. 1955 Beatrice Woods

NAVY DEPARTMENT
OFFICE OF NAVAL RESEARCH
NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

1 April 1941 NRL Report No. R-1717

NAVY DEPARTMENT

Report

on

Test of Underwater Reception
of Low Frequency Radio Signals.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

Number of Pages: Text - 11 Tables - 8 Plates - 28

Authorization: BuShips letter S67/46(10-18-DR6) of 23 October 1940 and 17 December 1940.

Date of Test: 20 December 1940 to 12 February 1941.

Tests Conducted by:

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Distribution:
- Bureau of Ships (10)
- OPNAV (2)
- Comdt. NYd. Wash (2)
- C.O. USS S-30 (1)

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26 Sept 1955 Beatrice Woods

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APPENDIX

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APPENDIX (Continued)

AUTHORIZATION OF TEST

1. The tests herein reported were authorized by Bureau of Ships letter, reference (a) and (b). Additional pertinent information was given in references (c) to (j) inclusive.

References:
- (a) BuShips ltr. S67/46 (10-18-DR6) of 23 Oct. 1940 to Director, NRL.
- (b) BuShips Ltr. S67/46 (10-18-DR6) of 17 Dec. 1940 to Director, NRL.
- (c) BuShips ltr. S67/46 (12-31-DR6) of 9 Jan. 1941 to Chief of Naval Operations.
- (d) Opnav. conf. ltr. (SC) S67 op-20-E/AB (063020) of 6 Sept. 1940 to BuShips.
- (e) BuShips conf. ltr. SS/S67 (9-6-DR6) of 25 Oct. 1940 to Opnav.
- (f) BuShips Ltr. S67/46 (10-18-DR6) of 24 Oct. 1940 to Comdt. NYd. Wash.
- (g) Comsubrolfor dispatch 131543 of Nov. 1940 to Comrolfor.
- (h) BuShips Ltr. S67/46 (12-31-DR6) of 2 Jan. 1941 to Opnav.
- (i) BuShips Ltr. S67/46 (12-31-DR6) of 15 Feb. 1941 to Opnav.
- (j) NRL Report R-1669.

OBJECT OF TEST

2. The object of the test herein reported was to investigate the practicability of equipping submarines with means and equipment to receive low frequency transmissions while completely submerged. To determine this, it was necessary to make the following tests:

- (a) The signal strength and signal to noise ratio received by various types of antennas at various depths and for various frequencies.
- (b) The best type of coupling device (input transformer and tuning unit) to transfer the received signals from the antennas to the receiver equipment.

In order to obtain other pertinent information other tests were made as follows:

- (1) Underwater bearing of transmitter by null method.
- (2) "Q" of loops.
- (3) Effect of Sea bottom on signals.
- (4) Noise survey of ship.

ABSTRACT OF TESTS

3. Except for the preliminary tests on the coupling transformer unit, the tests were performed on board the USS S-30, on which ship the test equipment had been installed. The electrical tests conducted to determine 2, above, were as follows:

(a) Characteristics of loop input transformer.

(b) Electrical characteristics of antenna systems.

(c) Loop "Q" 's and overall "Q" 's.

(d) Microvolts input to loops, microvolts input to the receiver, and signal to noise ratio for various depths of submergence for each antenna

(e) The same as (d) for different radio frequencies.

(f) The same as (d) for bay water and ocean water.

(g) Effect of depth of ocean bottom on received signals.

(h) Directional effect of "Yard" loop on received signals.

(i) Noise survey of ship's superstructure.

CONCLUSIONS

(a) The results of this investigation show that underwater reception of low radio-frequency signals is feasible. With the equipment used, signals of 1000 microvolts per meter in air should be readable to a depth of 34 feet (above loop) in ocean water and 38 feet (above loop) in water of less salinity (similar to Chesapeake Bay water at Smith's Point). This, as pointed out by Bureau of Ships (reference (i)) would be the approximate depth for usable signals from NSS(17.8 Kcy) at 2000 miles, predicated on the basis of no atmospherics. Further at periscope depths (loop depth 10 feet), a field strength of only 30 microvolts per meter in air would be needed for this same frequency, which would be a distance for NSS of 7000-8000 nautical miles, again predicated by the absence of static. These calculations have been made on the basis of a one to one signal to noise ratio and are therefore near the limit of readable signals; however, as indicated above, static has not been considered, and will be the limiting factor for summer time conditions and in the tropics and will materially reduce the range for readable signals either on the surface or submerged; on the other hand, as indicated below in (c), the ship's noise was the limiting factor, reduction of which would make for a greater depth of readable signal under ideal atmospheric conditions. In considering static as a limiting factor it is assumed that the ratio of signal to static will not materially change whether reception is accomplished from a submerged, or an above water, loop collector.

(b) The concentrated loops, "Yard" and "DQ", although not supplying as many microvolts to the receiver as the clearing line loops, were more efficacious because of the lower noise level. The "Yard" loop was the better of the two.

(c) With the equipment used, the ship's noise was the limiting factor for depth of submergence. For a given receiver sensitivity (high enough to produce noise on all loops), the grounded Aft. loop had the greatest noise, next being the Forward loop, and then the "Yard" loop, with slightly greater noise than the "DQ" loop. This is as might be expected, considering the relative coupling of the various loops to the hull, in which there is known to be large induced currents. This induced current could be expected from the use of the powerful d.c. machinery inside the hull. Another source of this induced hull voltage might possibly be from the electrolytic action set up by dissimilar metals of the ship when in salt water. For instance, the difference in potential between copper and iron in sea water is .13 volts and between brass and iron, it is .17 volts. Inasmuch as the limiting noise was worse in the ocean than in the bay, there may be some basis for this last premise. It might be possible with improved positioning of a concentrated loop and with shorter, better shielded leads, to reduce the noise pick-up. Probably the noise factor would be a problem for each type of submarine, if not for each individual vessel.

(d) The input coupling transformer is of satisfactory design. It gives a coupling of about 70 to 85%, which, combined with its high "Q", gives a very good overall "Q" and voltage step-up for the whole system. It was found that a slight mismatch of the input impedance (lower impedance than loop) gave an improved "Q" x step-up ratio with a decreased "Q" of loop, as in submergence. An improvement of "Q" x step-up ratio might be secured by a better molybdenum-permalloy core; on the other hand, a well designed transformer with a commercial iron-dust core might give somewhat poorer results at an appreciable saving in cost but an increase in size.

(e) The depth of sea bottom seems to have practically no effect on the received signal strength.

(f) The directional effect of the "Yard" loop (presumably the same with the other loops) is quite pronounced. Signals from NBA show a very marked minimum with the plane of the loop at 90° from the station bearing. Bearings can be taken with good accuracy. In this connection, it is to be noted that maximum submergence for a given station can be secured only when the loop is on the "maximum" of the station or within approximately $\pm$ 10° or + 180° $\pm$ 10° of this bearing. The loops on the USS S-30 were fixed in position, and mounted with the plane of loop parallel to the longitudinal axis of the ship. It also should be noted that it may be possible that the hull of the ship itself may pick up some signal and reflect this into the loop, consequently a rotatable loop cross ways of the ship might not produce in the receiver the signal strength as indicated in this report. Even though this were true, a loop placed well above the deck probably would not be so affected because of the rapid attenuation of the signals by water.

(g) The experimental data checks very well with the theoretical attenuation of signals with depth for various frequencies. The lower the frequency, the lower the attenuation. For the example given in (a) above, (1000 microvolts in air giving a loop depth of 34 feet at 17.8 Kcy), 6000 microvolts would be required for the same depth at 32.8 Kcy.

(h) The best physical shape of the loop for underwater reception is not the same as in air but is long and narrow, with the long side parallel to the surface of the water. However, the gain in signal strength over that for a conventional loop may not be worth while because of mechanical considerations. (Plate 28) Further loop design characteristics were not made in these tests. However the loop "Q" 's, characteristics, and effectiveness combined with NRL Report R-1669 (reference (j)) may be used as a starting point in the design of the best loop for underwater low radio-frequency receptions.

(i) It is to be noted that no natural static entered into the results of the tests.

(j) Summary of factors entering into the underwater reception of low frequency radio signals.

(1) The lower the frequency, the greater the submergence possible for a given surface field strength.

(2) Bearing of the loop.

(3) Location of loop for least ship's noise pick up.

(4) Design of loop, including "Q", effective height, and physical shape.

(5) Design of coupling unit, including "Q", coupling ratio, and impedance values.

(6) Coupling to receiver.

RECOMMENDATIONS

The tests as herein recorded indicate that the equipment, as installed on the USS S-30 is capable of satisfactory underwater reception of low radio-frequency signals. There are certain improvements that might be made. With this in view, the following recommendations are made:

(a) That underwater reception of low radio-frequency signals be considered as practicable and useful for communication if due regard is placed on depth limitations, which are governed by the frequency employed and the field strength at the surface.

(b) That in such installations a loop of optimum electrical characteristics compatible with the necessary mechanical features be designed, the "Yard" loop being used as a reference from which to start.

(c) That consideration be given to the desirability of rotating said loop both for bearing purposes and for obtaining the maximum signal strength without the necessity of turning the ship.

(d) That consideration be given to the design of the input coupling transformer as to whether maximum efficiency must be had or if a lower efficiency can be tolerated with a possible decrease in the unit cost.

(e) That consideration be given to the input circuit design of the receiver used, in order to maintain a high overall "Q" of the system.

(f) That consideration be given to the possible methods of reducing the interfering "ship's noise".

MATERIAL UNDER TEST

4. The material under test consisted of the following:

(a) One - Input coupling device. The input coupling unit to the RAK receiver was essentially a tightly-coupled transformer with the secondary tuned by a 1000 micromicrofarad variable condenser. In order to get the most signal strength possible out of the loop systems, it was necessary to keep the "Q" and coupling coefficient as high as possible; for this reason high permeability iron (Western Electric 2-81 molybdenum permalloy) was used as the transformer core. The primary and secondary consisted of pie windings alternated to give as near unity coupling as possible. Universal-wound litz wire coils were used. The transformer was thoroughly impregnated in Superla Wax. The primary was tapped so that an input impedance of either 22 or 114 microhenries could be obtained to match the loops. The secondary inductance was 303 millihenries. Due to the high impedance-ratio, a reasonably small variable capacitor could be used to tune the loop. The output of this system coupled to the grid of the first r.f. tube of the RAK, while the ground return was made through a 5 megohm resistor to the grid return of this tube. Made by the Naval Research Laboratory. (Tables 1 and 2 and Plates 26, 27, and 28).

(b) One - RAK receiver. This was a standard type RAK, with the input coupling transformer connected to the grid of the first tube. (No. RV 46044 Serial 512) Manufactured by R.C.A. (Plate 28)

(c) One - Clearing Line Loop (grounded to the hull). Referred to hereinafter as the Aft Clearing Line Loop, it was made of rubber covered wire secured by marlin line to the aft clearing line. The wire was No. 6 with approximately 3/16 inch insulation (1/2" O.D. approx). It was well grounded to the ship's hull at the foot of the aft stanchion while the "high" end was brought down from the clearing line to the regular ship's radio lead-in insulator. The approximate length was 55 feet with the height of the high and low ends of the flat top portion being respectively 10 feet and 4 feet above the deck. (Plate 23, Tables 3 and 4)

(d) One - Clearing Line Loop (ungrounded) Referred to hereinafter as the Forward (Fore) Clearing Line Loop, it was regular submarine loop cable secured by porcelain clamps to the forward clearing line. This was seven conductor No. 10 wire with approximately 3/4" rubber insulation, the outside diameter being approximately 2 inches. The "high" end was brought down from the "A" frames to the ship's radio lead-in insulator while the "low" return was laid along the deck (secured thereto by marlin line) and brought up through the conning tower structure to the ship's radio lead-in insulator. The approximate length was 69 feet with the heights of the high and low ends of the flat top portion being respectively 14 feet and 5 feet above the deck. (Plate 23, Tables 3 and 4)

(e) One - "DQ" Loop. This was a standard Naval direction-finder loop mounted on the starboard side of the ship just aft of the conning tower. This loop is made of 8 turns of stranded wire (equivalent to #16 B S gauge), having a mean diameter of 20.5 inches. (Plate 23, Tables 3 and 4).

(f) One - "Yard" Loop. This loop was made by the Radio Laboratory of the Washington Navy Yard to the suggested specifications of the Naval Research Laboratory. It was made up of 21 turns of No. 10 rubber covered wire (#121 packard cable) in a loop of 21 inches, outside diameter, 18 inches - inside diameter. This was placed inside of a loop shaped box made of 1" oak boards 22 inches in overall dimensions with cross section of 3 - 1/2 inches. This box was placed inside a second loop shaped box made of 1" oak boards, 30 inches in overall dimensions with a cross section of 9 inches. The space between was filled with Ozite. This loop was mounted similarly to the "DQ" loop but on the port side of the ship. The lead-in wires, as in the "DQ", passed into the conning tower through a specially made stuffing box. The lead-in wires then going through the conning tower hatch into the control room and to the receiving equipment located on the gyroscopic compass table. (Plates 23 and 24, Tables 3, 4 and 5).

METHOD OF TEST

5. The following instruments or apparatus were employed in conducting the tests described herein:

(a) Standard Signal Generator, General Radio Model LN CAG 60004 - Serial 18.

(b) Output Meter, General Radio Company, 483C - No. 92.

(c) Output Meter, Ballantine, Model 300 - No. 14.

(d) Oscillograph, Dumont, Model 168 - No. 927.

(e) "Q" Meter (Modified for 17 Kcy.), Boonton Radio Company 100A - No. 177.

(f) Condenser Bank, No. 14, Pattern 1797 - No. 2073.

6. The loops were installed on the USS S-30 by the Radio Laboratory of the Washington Navy Yard. The lead-ins for the "Yard" and "DQ" loops were brought into the ship through a special stuffing box in the conning tower, while, for those of the clearing line loops, use was made of the ship's regular radio lead-in insulators. On the S-30, these are mounted

aft of the conning tower near the "A" frames, to which the top end of the clearing line loops were secured.)Plates 23 and 24).

7. During these tests the USS S-30 operated out of Annapolis, Maryland. A preliminary test was made on 20 December 1940 to determine if any changes or further equipment were necessary for the tests.

8. Regular tests were made during January and February 1941 as follows:

(a) January 6-9. Near Smith's Point in Chesapeake Bay. Area 76° 11' W between 37° 43' N and 37° 51' N.

(b) January 13-17. Off the Virginia Capes. Area 76° 11' W 36° 35' N on a bearing of 153° for a distance of 25 nautical miles.

(c) February 17-20. Near Smith's Point in Chesapeake Bay. Area 76° 11' W between 37° 43' N and 37° 51' N.

9. Tests were made on special transmission from stations NBA - 24 Kcy. and NSS - 15.44, 17.8 and 32.8 Kcy., as well as tests on these stations and on NCI - 18.4 Kcy. during their regular schedules.

10. By means of a switch on the coupling device, any of the loops could be coupled to the proper input impedance of the input transformer. A second switch made it possible to insert the terminals of the signal generator in the circuit of the loop under test or connect them directly to the receiver terminals. This switch also permitted the coupling of the "Q" meter to the secondary of the input transformer for making secondary "Q" measurements.

11. The "Q" of the loops was measured, using the "Q" meter as a source of 17 Kcy. r.f. and the Ballantine Meter to measure the input and loop voltages. The "Q" was taken as the ratio of loop voltage to the input voltage. A condenser bank of 2 microfarads total capacity was used to tune the loop to 17 Kcy.

12. An output meter with 600 ohms termination was used to indicate the standard output and the noise level of the receiver. It was also used in conjunction with the RAK sensitivity control to measure the attenuation of signal with submerged depth.

13. It was found in the preliminary tests that the best receiver (RAK) adjustment for all conditions was as follows:

(a) R. F. Trimmer -- 50.
(b) Regeneration Control - 3.
(c) AVC - Off.
(d) R.F. Tuning - On, 770 - 1300 position 3.

14. In measuring the microvolts to the loop and to the receiver, readings for a given test (frequency and station) were taken for all loops at a given depth and then for other succeeding depths. (See Table 7 for a condensed sample of readings.) Actually the ship, when submerged, might not maintain a given depth for all loop readings so that the actual depth was recorded when adjustments of the receiver were made. The complete list of readings taken are as follows: Date and Time; Bearing; Signal Identification; Signal Frequency; Tuning Unit - Selector Switch (Loop), and Dial Setting; Receiver-Band, Frequency Dial, Regeneration Control, Sensitivity Control, R.F. Trimmer, and A.F. Tuning; Output-Signal and Noise on Tuning, Noise only on tuning, Signal and Noise with S. G. in Primary and Noise only with S. G. in Primary; Signal Generator-Primary Reading and actual microvolts and receiver reading and actual microvolts; Location of submarine; "Q" Meter - Secondary "Q", Capacity and "Q" Meter Dial.

15. Though the method used in 14, above, would give the attenuation of signal with depth, separate dives were also made in which the output signal was read on the output meter for every 2-foot depth from the surface down to the limiting noise level. When the output volts dropped off by an order of 10, the sensitivity of the receiver was readjusted so that the run could be continued. In calculating the resultant output the noise volts were subtracted from the signal and noise reading.

16. In the test of the effect of the sea bottom, the ship traveled at a constant submerged depth (periscope depth ± 2 ft., loop depth 9 ± 2 ft.) for a distance of 25 nautical miles which covered a sea bottom depth of 20 to 500 fathoms. Output meter readings were taken continuously, the submerged depth being recorded for each reading.

17. In testing for the bearing of the transmitting station, the ship was moved through a 360° arc.

18. A noise survey was made of the ship's superstructure by utilizing a loop, connected by a long two wire shielded microphone cable, to the input coupling transformer. The test loop was coupled as closely as possible to the metal of the deck and superstructure to determine any particular noise spot. In this test various speeds (electric drive) were tried. Also during actual diving operations, a test of noise was made under different actual diving procedure.

DATA RECORDED

19. Complete data were recorded for all tests conducted. This information is contained in Tables 1 to 8 and Plates 1 to 28, inclusive.

PROBABLE ERRORS

20.	Submerged depth	± 1'
	Microvolts received Signal	± 10%
	Signal/Noise ratio	± 10%
	Output Meter Reading	± 10%

RESULTS OF TEST

21. Microvolts to the receiver with submergence depth. The clearing line loops, due to their large size, supplied a greater value of microvolts to the receiver than the small concentrated loops; however, due to the greater noise pick-up in the clearing line loops, reception of signals was not as satisfactory at as great depths as on the small loops. This was true both in the bay and ocean. Unfortunately, in the ocean tests, the ship's batteries were low so that the receiver voltage was down 30%. A later check indicated that, with normal voltage, the mocrovolts to the receiver should be increased by 14% with no increase in the signal/noise ratio. The results for the ocean tests have been corrected for this. The limiting noise was of two main types - commutator noise and crashes. The commutator noise was present only occasionally while the crashes were present on high receiver sensitivity on the clearing line loops and to a lesser extent on the small loops. (See Plates 1 to 11, inclusive.)

22. Field Strength in Air with Depth of Receivable Signals. These curves were calculated from Plates 1 to 11, inclusive, and from the known field strength of NBA in Chesapeake Bay, assuming a possible readable signal having a 1 to 1 signal to noise ratio. (Plates 14 to 19, inclusive).

23. Experimental Proof of the Theoretical Attenuation. The experimental results of attenuation with depth and frequency check within experimental error with the theory (reference (j)). (Plates 12 and 13).

24. The effect of the depth of the sea bottom. The depth of the sea bottom seems to have practically no effect on the strength of the signals. (Plates 20 and 21).

25. Determination of Station Bearing by "Swinging" the Loop Antenna. A test of the bearing of NBA with the "Yard" loop, both on the surface and at periscope depth (13' to loop, 45' to keel) checks perfectly with the true bearing and is indicated by a very sharp minimum. (Plate 22)

26. Test of Forward Clearing Line Loop. In order to determine the best type of clearing line loop, measurements were made of microvolts input to the receiver with the Forward Clearing Line Loop as originally installed, with the loop cut and grounded to the hull at the forward end, and with the loop cut and left open at the top of the forward stanchion. Best results were had in the original method as more noise and less signal were received in the other cases. When used open as a flat top antenna the signal strength was down to one tenth of the original. However, in this latter case, proper matching was not obtainable; when connected directly to the receiver without the loop transformer, no signals could be heard at 60 feet (keel depth, 27 feet, loop depth). (Table 7).

27. Noise Survey. A test was carried out to try to determine the source of the ship's noise but this was inconclusive in results. A test loop, connected to the receiving equipment by a two wire shielded line, was

carried above on the ship's deck and superstructure. It was coupled as closely as possible to the metal structure but no change in noise was noted for various positions on this structure or with various speeds (electric drive). A further test with the loop closely coupled to the inside of the hull was made during a dive. With the receiver adjusted to give over one half volt of noise, no change was noted during various diving operations. These operations included various speeds, operation of diving vanes, operation of steering rudder motor, operation of ballast pumps, and a complete stop of all equipment. The wiring of this ship is very old and continuous checking is made to eliminate extraneous "grounds" consequently as none of the severe "crashes", obtained in the ocean tests, were present it may be possible that these crashes arose from some intermittent "ground". However, it is felt that the results as indicated above are not conclusive in any way. (Table 8).

26. Theoretical considerations of the design of a loop for underwater reception suggested by reference (j) indicate that a narrow loop with its long side parallel to the water surface is best. This is more pronounced the larger the loop. (Reference (j) and Plate 2a).

CONCLUSIONS

29. The results of this investigation show that underwater reception of low radio-frequency signals is feasible. With the equipment used, signals of 1000 microvolts per meter in air should be readable to a depth of 34 feet (above loop) in ocean water and 38 feet (above loop) in water of less salinity (similar to Chesapeake Bay water at Smith's Point). This, as pointed out by Bureau of Ships (reference (i)) would be the approximate depth for usable signal from NSS (17.8 Kcy) at 2000 miles, predicated on the basis of no atmospherics. Further, at periscope depths (loop depth 10 feet), a field strength of only 30 microvolts per meter in air would be needed for this same frequency, which would be a distance for NSS of 7000-8000 nautical miles, again predicated by the absence of static. These calculations have been made on the basis of a one to one signal to noise ratio and are therefore near the limit of readable signals; however, as indicated above, static has not been considered, and will be the limiting factor for summer time conditions and in the tropics and will materially reduce the range for readable signals either on the surface or submerged; on the other hand, as indicated below in 31, the ship's noise was the limiting factor, reduction of which would make for a greater depth of readable signal under ideal atmospheric conditions. In considering static as a limiting factor it is assumed that the ratio of signal to static will not materially change whether reception is accomplished from a submerged, or an above water, loop collector.

30. The concentrated loops, "Yard" and "DQ", although not supplying as many microvolts to the receiver as the clearing line loops, were more efficacious because of the lower noise level. The "Yard" loop was the better of the two.

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(a) The lower the frequency, the greater the submergence possible for a given surface field strength.

(b) Bearing of the loop.

(c) Location of loop for least ship's noise pick up.

(d) Design of loop, including "Q", effective height, and physical shape.

(e) Design of coupling unit, including "Q", coupling ratio, and impedance values.

(f) Coupling to receiver.

TABLE 1

Electrical Constants of Loop Input Transformer

Transformer Section	Connections	Resistance Ohms	Inductance Microhenries	"Q" 1000 Cycles	"Q" 17 Kcy	Coefficient of Coupling
A	1-2	.080	114	7.2	47	.858
	1-3	.040	22	2.4	---	.71
	2-3	.040	41	4.3	28	.744
B	1-2	.080	114	7.0	46	.865
	1-3	.037	22	2.5	---	.715
	2-3	.043	41	4.0	26	.91
A + B	1-2+1-2		428	15	72	.89
Secondary		75.2	303 milli-henries	27	105	

Note: Section A 1-3 used for low impedance loops ("DQ", etc.) and Section A 1-2 used for higher impedance ("Yard" loop)

TABLE 2

Measurement of "Q" x Step-up Ratio at 17 Kcy.

Transformer Pri. Inductance Microhenries #1 Simulating Loop	#2	"Q" x Step-up Ratio No. added R.	R Added	Res. Added Ohms
468	428	660	190	5
	114*	670	300	5
	41	500	320	5
	22	380	300	5
123	114	1200	440	1
	41*	1160	600	1
	22	1100	640	1
44	41	1680	880	1/3
	114	1000	480	1/3
	22	1560	720	1/3

*Condition used in Tests on USS - S-30

CONFIDENTIAL

TABLE 3

Electrical Constants of Loops on USS S-30

Loop	Inductance Microhenries	Resistance to Ground Megohms
"Yard"	550	1400 - 1800
"DQ"	90	5000 - 8000+
Aft. CL. (grounded)	45	
For. CL.	70	4.2

TABLE 4

"Q" of Loops on USS S-30

Loop	"Q" Air	"Q" Submerged Bay	"Q" Submerged Ocean	Effective Secondary "Q"* Air	Effective Secondary "Q"* Submerged Bay	Effective Secondary "Q"* Submerged Ocean
"Yard"	74	50	43	60	50	45
"DQ"	6.7	5.4	3.7	30	20	--
Aft CL(gr.)	11	**	3.3	40	--	--
For. CL	16	7.85	7	50	30	20

*Measured in secondary of coupling transformer. Readings below 30 were estimated. -- Readings too low to measure.

**No reading taken.

TABLE 5

"Q" of Yard Loop with Submerged Depth
(Bay Water)

Loop Depth Feet	Q
Surface	70
0*	55 ± 5
4'	50
9'	43
10'	47
10'	50

*Waves breaking over loop.

TABLE 6

Sample Set of R adings

Depth Gauge (Depth to keel) feet	Loop	Sensitivity Reading	Output: Sig. + noise on tuning Volts	Output: Noise only Volts	Output: Sig. + noise S.G. in Sec. Volts	Output: Noise only Volts	Signal Generator Primary: Reading	Signal Generator Primary: Actual Micro-volts	Signal Generator Secondary: Reading	Signal Generator Secondary: Actual Micro-volts
Surface	"Yard"	8.3	1.9	0	1.73	0	930	4.05	2300	1150
"	"DQ"	8.5	1.9	0	1.8	0	280	1.22	1400	700
"	ACL	6	1.9	0	1.75	0	6500	28.3	95000	15800
"	FCL	6.1	1.9	0	1.76	0	5300	23.1	98000	16300
40	"Yard"	8.8	1.9	.3	1.7	.2	270	1.18	670	335
"	"DQ"	9.0	1.9	.1	1.65	.1	130	.57	550	225
"	ACL	8.3	1.9	.7	1.7	.6	400	1.74	2000	1000
"	FCL	8.0	1.9	.1	1.8	.2	450	1.91	2000	1000
50	"Yard"	9.2	1.9	.3	1.8	.3	63	.27	310	155
48	"DQ"	9.6	1.9	.2	1.75	.1	20	.087	96	48
48	ACL	—	—	—	—	—	—	—	—	—
48	FCL	8.3	1.9	.1	1.8	.2	340	1.48	2300	1150
62	"Yard"	9.8	1.9	.8	1.8	.7	14	.061	51	25
60	"DQ"	10.0	.7	.3	.7	.3	4	.017	18	9
60	ACL	—	—	—	—	—	—	—	—	—
60	FCL	9.0	1.9	.4	1.7	.3	55	.24	370	185
70	No signals any loop									

TABLE 7

Result of Changes in Forward Clearing Line Loop
(NCI - 18.4 Kc. in Day -- Bearing 0°)

Loop	Depth to keel feet	Depth to loop feet	Sensitivity Reading	Output Sig.& Noise volts	Output Noise Only	Microvolts To Loop	Microvolts To Receiver
Complete loop	40	7	6.7	1.9	0	23.2	8150 *
	60	27	7.3	1.9	.1	4.35	1300
	70	37	7.8	1.9	.2	4.35	1100
Cut and grounded	40	7	7.3	1.9	0	10.9	4700
	60	27	8.0	1.9	.3	2.61	600
	70	37	8.3	1.9	.8	.78	400
Cut and open	40	7	8.1	1.9	.15	- -	500
	60	27	8.8	1.9	.9	- -	120

* Keying dots

Note: With open loop connected to secondary of transformer (grid of tube) no signal obtained at 60 feet (to keel).

TABLE 8

Noise Survey

Test Loop Outside

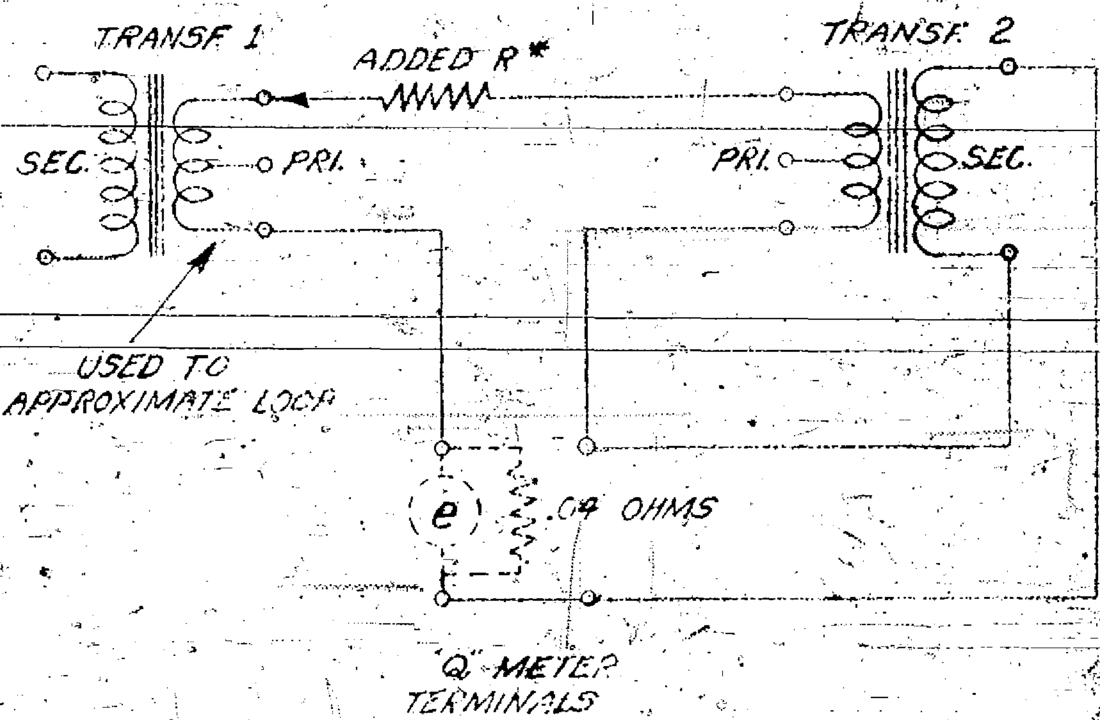
Receiver Sensitivity	Operation	Output	Remarks
9.	Slow speed	.7)	Same over all parts
9.	Normal speed	.7)	of deck and superstructure

Test Loop Inside *

9.	Normal speed	.6 - .9
9.	Fast speed	.6 - .9
9.	Stop	.9
9.	Slow speed	.6 - .9
9.	Trim pumps	.6 - .9
9.	Diving vanes	.6 - .9

* Closely coupled to metal hull.

CIRCUIT DIAGRAM
FOR
MEASUREMENT OF "Q" x STEP-UP RATIO



* USED TO SIMULATE REDUCED Q AS IN SUBMERGENCE

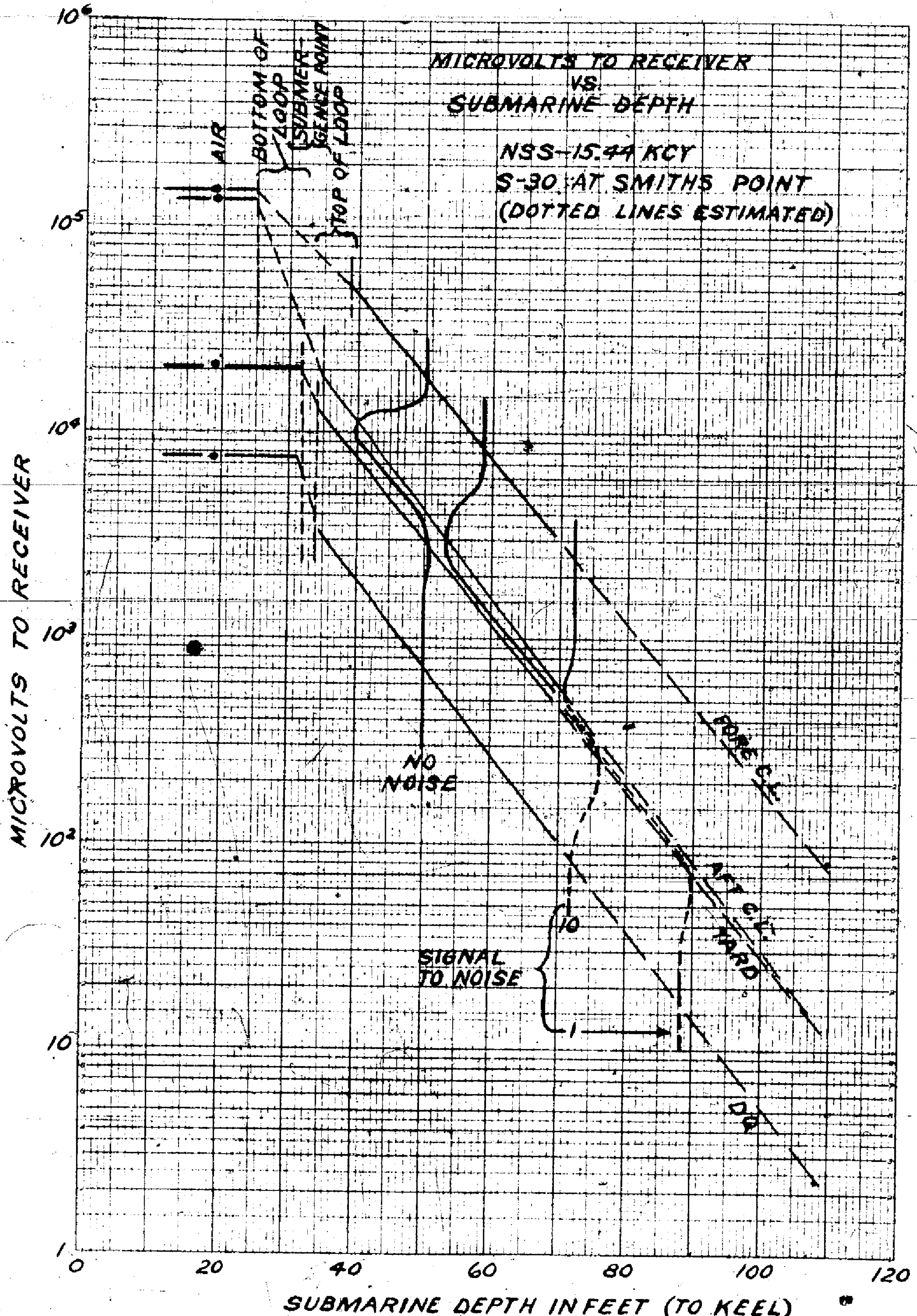

MICROVOLTS TO RECEIVER
VS.
SUBMARINE DEPTH
NSS-15.44 KCY
S-30 AT SMITHS POINT
(DOTTED LINES ESTIMATED)
AIR
BOTTOM OF LOOP
SUBMERGENCE POINT
TOP OF LOOP
NO NOISE
SIGNAL TO NOISE
10
1
FORE C.L.
AFT C.L.
HARD
DQ
MICROVOLTS TO RECEIVER
SUBMARINE DEPTH IN FEET (TO KEEL)
10^6
10^5
10^4
10^3
10^2
10
1
0
20
40
60
80
100
120

PLATE 1

CODEX BOOK COMPANY, INC. NORWOOD, MASSACHUSETTS

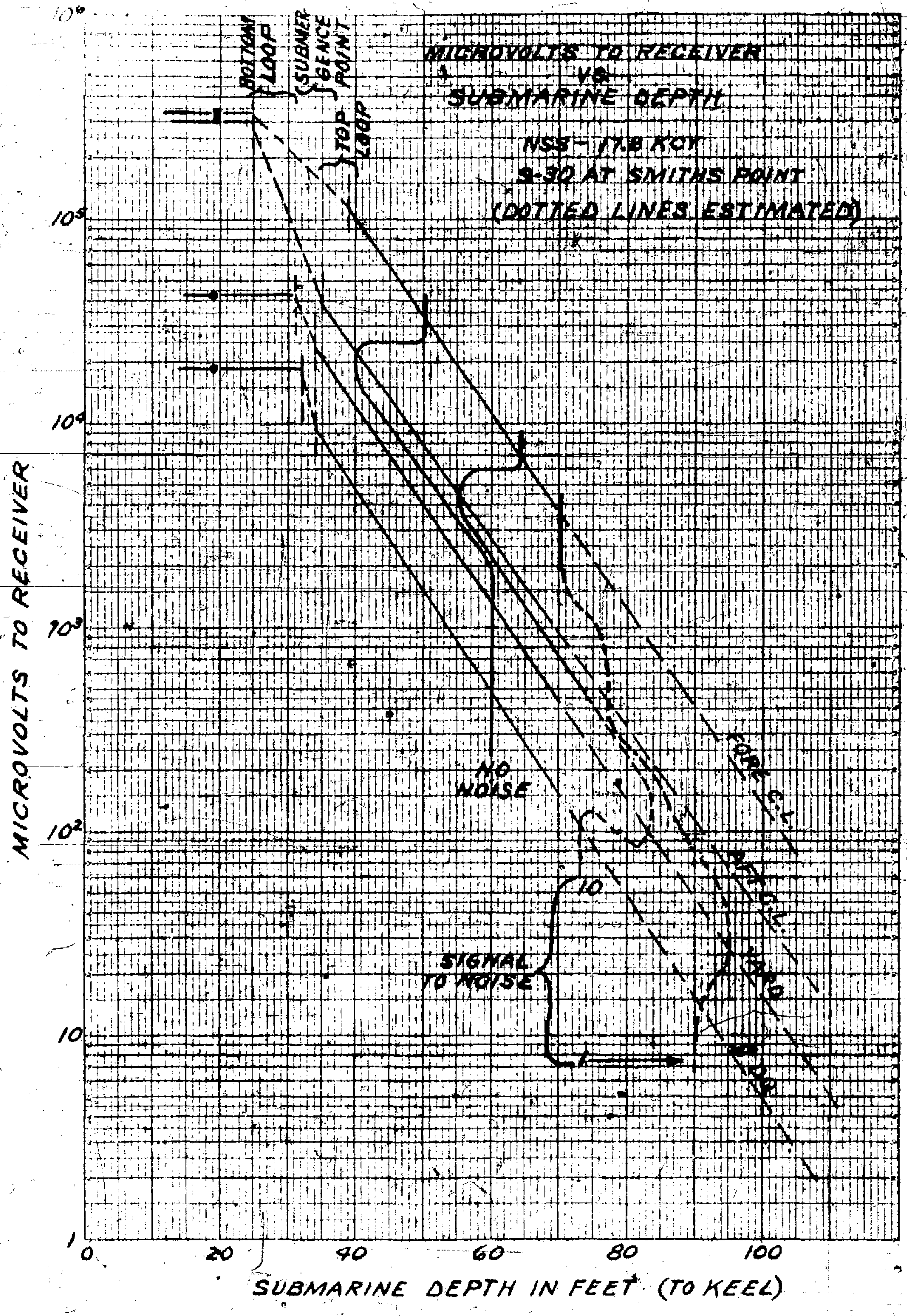
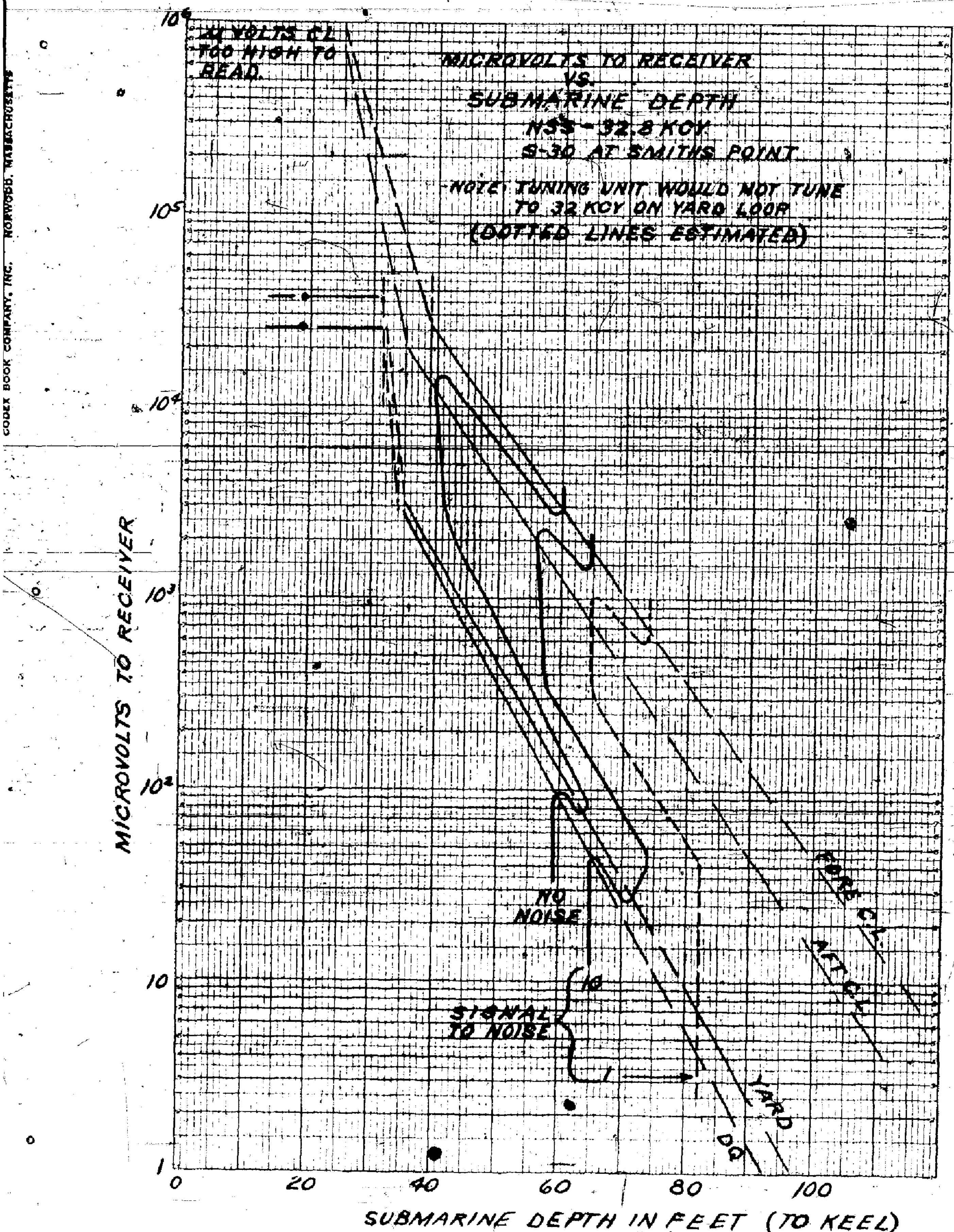
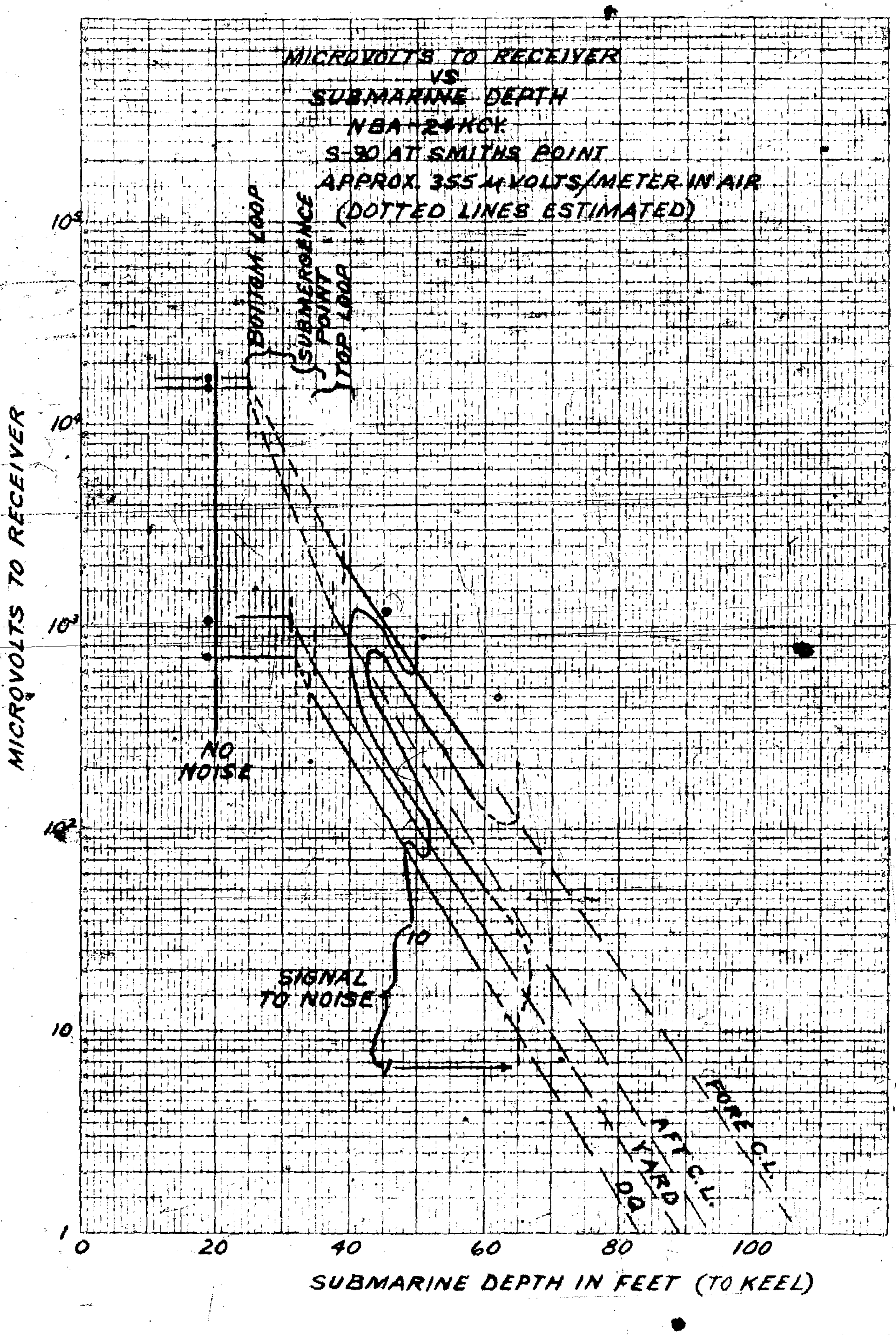


PLATE 2



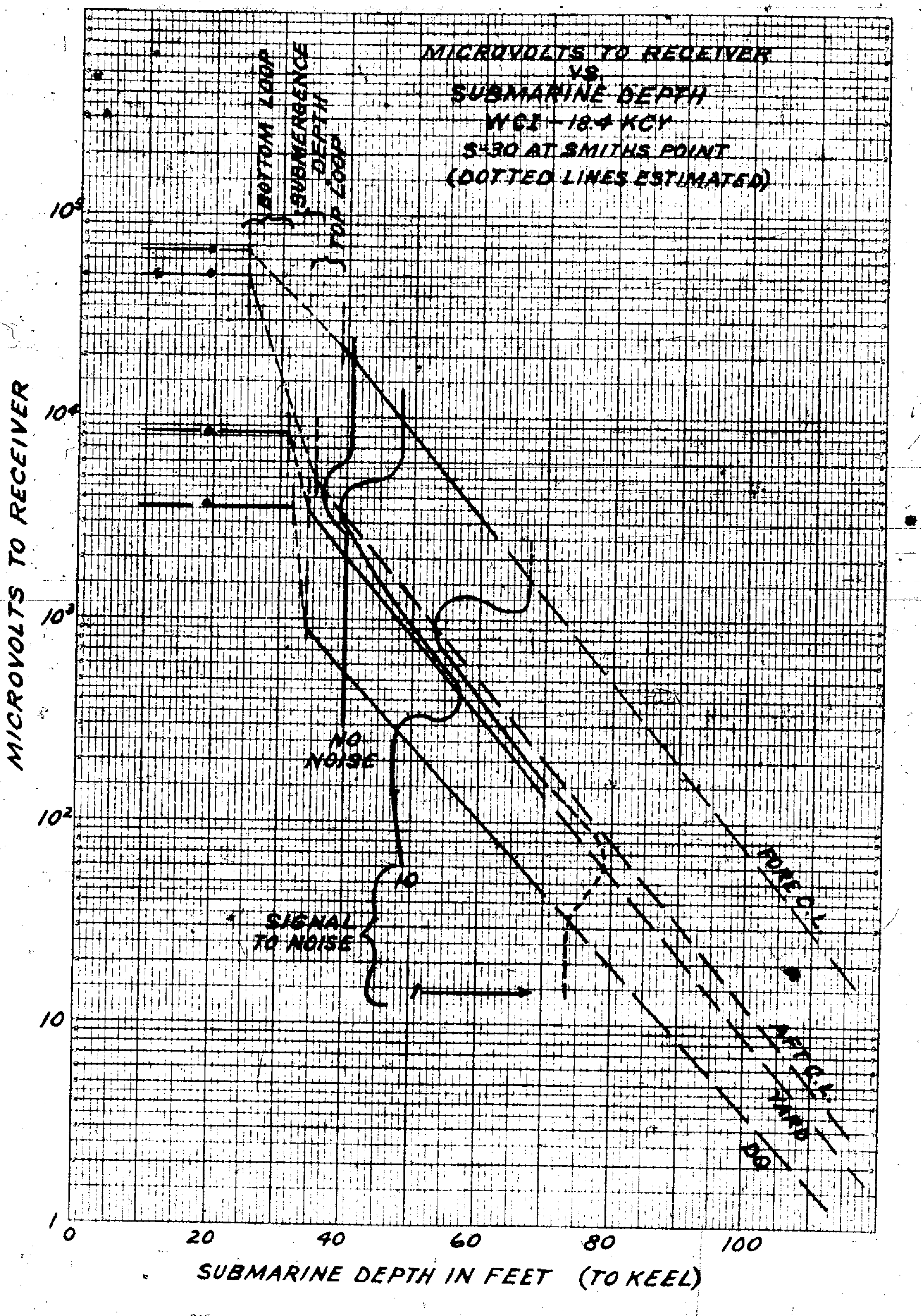
CODEX BOOK COMPANY, INC. NORWOOD, MASSACHUSETTS
MICROVOLTS TO RECEIVER
VS.
SUBMARINE DEPTH
NSS - 32.8 KCY
S-30 AT SMITHS POINT
NOTE: TUNING UNIT WOULD NOT TUNE
TO 32 KCY ON YARD LOOP
(DOTTED LINES ESTIMATED)
24 VOLTS C.L.
TOO HIGH TO
READ.
NO
NOISE
SIGNAL
TO NOISE
10
1
FORE C.L.
AFT C.L.
YARD
DG
MICROVOLTS TO RECEIVER
SUBMARINE DEPTH IN FEET (TO KEEL)

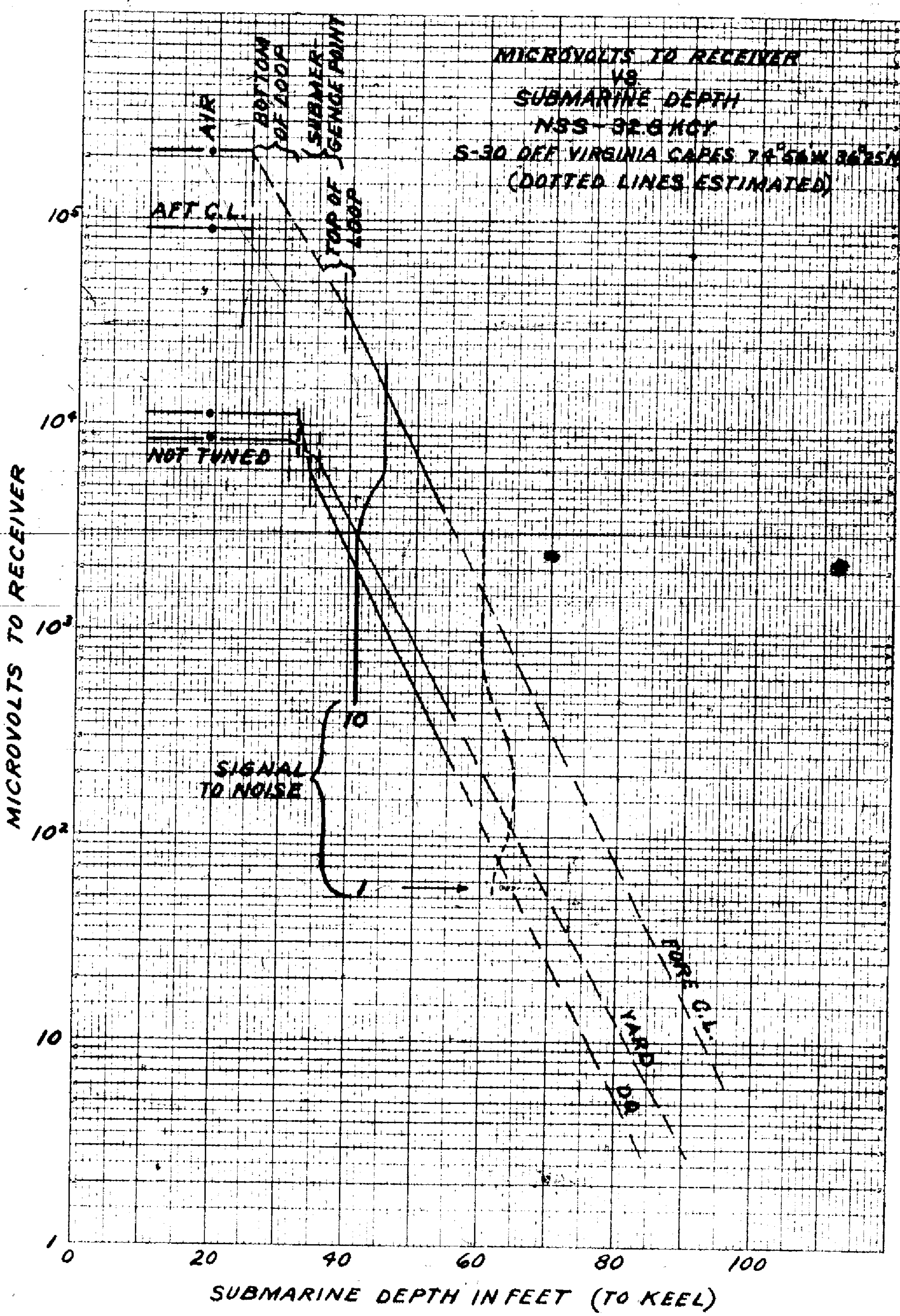
PLATE 3



MICROVOLTS TO RECEIVER
VS
SUBMARINE DEPTH
NBA - 24 KCY.
S-30 AT SMITHS POINT
APPROX. 355 μ VOLTS/METER IN AIR
(DOTTED LINES ESTIMATED)
BOTTOM LOOP
SUBMERGENCE POINT
TOP LOOP
NO NOISE
SIGNAL TO NOISE
10
1
FORE C.L.
AFT C.L.
YARD
O.A.
MICROVOLTS TO RECEIVER
SUBMARINE DEPTH IN FEET (TO KEEL)

PLATE 4


MICROVOLTS TO RECEIVER
VS.
SUBMARINE DEPTH
WCI - 18.4 KCY
S-30 AT SMITHS POINT
(DOTTED LINES ESTIMATED)
BOTTOM LOOP
SUBMERGENCE DEPTH
TOP LOOP
NO NOISE
SIGNAL TO NOISE
10
FORE C.L.
AFT C.L.
YARD
DG
MICROVOLTS TO RECEIVER
SUBMARINE DEPTH IN FEET (TO KEEL)
0
20
40
60
80
100
1
10
10^2
10^3
10^4
10^5



MICROVOLTS TO RECEIVER
VS
SUBMARINE DEPTH
NSS - 32.8 KCY
S-30 OFF VIRGINIA CAPES 74°56W 36°25N
(DOTTED LINES ESTIMATED)
AIR
BOTTOM OF LOOP
SUBMERGENCE POINT
TOP OF LOOP
AFT C.L.
NOT TUNED
SIGNAL TO NOISE
10
FORE C.L.
YARD
D.
MICROVOLTS TO RECEIVER
10^5
10^4
10^3
10^2
10
1
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)

PLATE 6

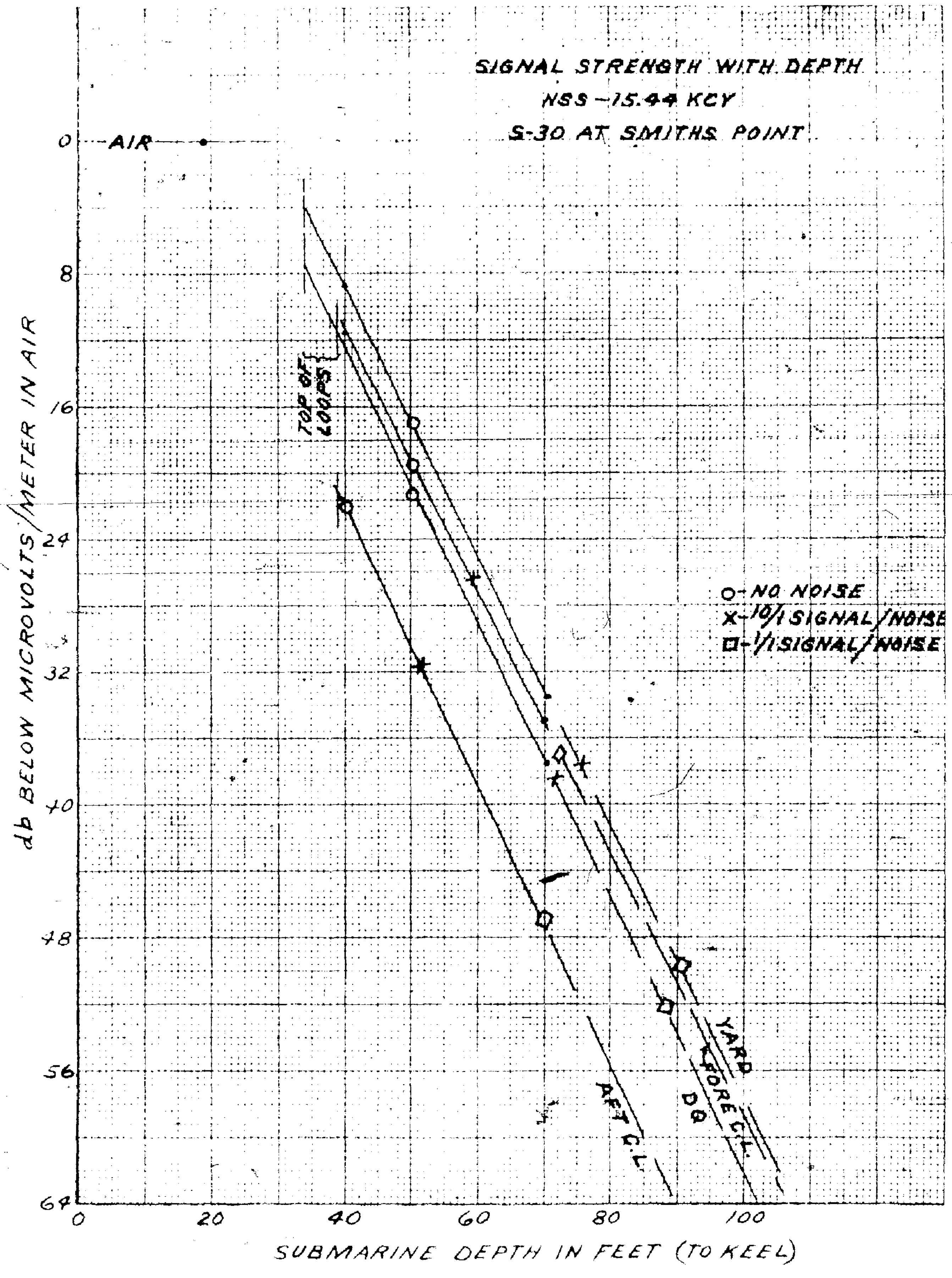

SIGNAL STRENGTH WITH DEPTH
NSS – 15.44 KCY
S-30 AT SMITHS POINT
AIR
TOP OF LOOPS
o - NO NOISE
x - 10/1 SIGNAL/NOISE
□ - 1/1 SIGNAL/NOISE
YARD
FORE C.L.
DQ
AFT C.L.
db BELOW MICROVOLTS/METER IN AIR
0
8
16
24
32
40
48
56
64
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)

PLATE 7

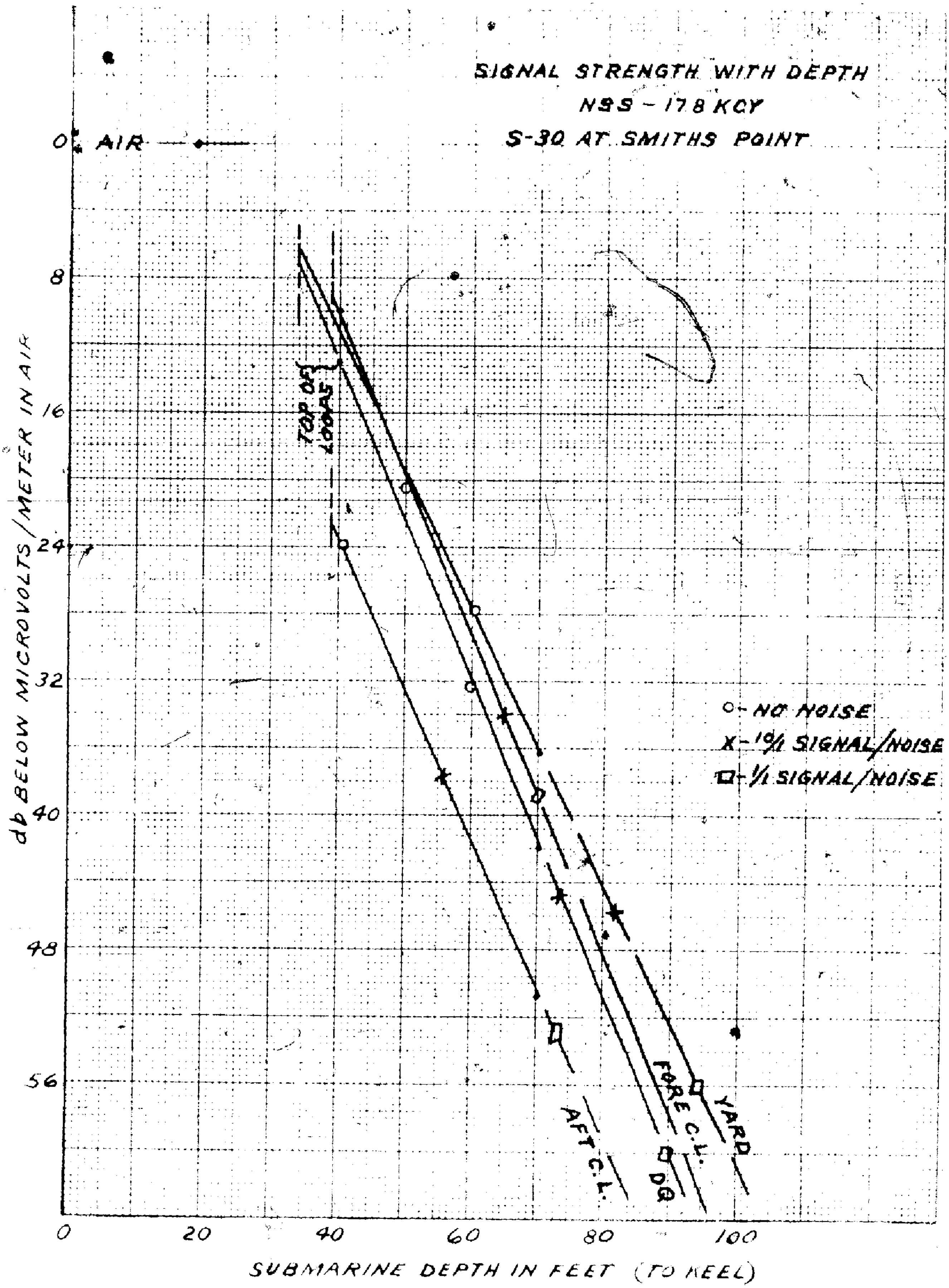
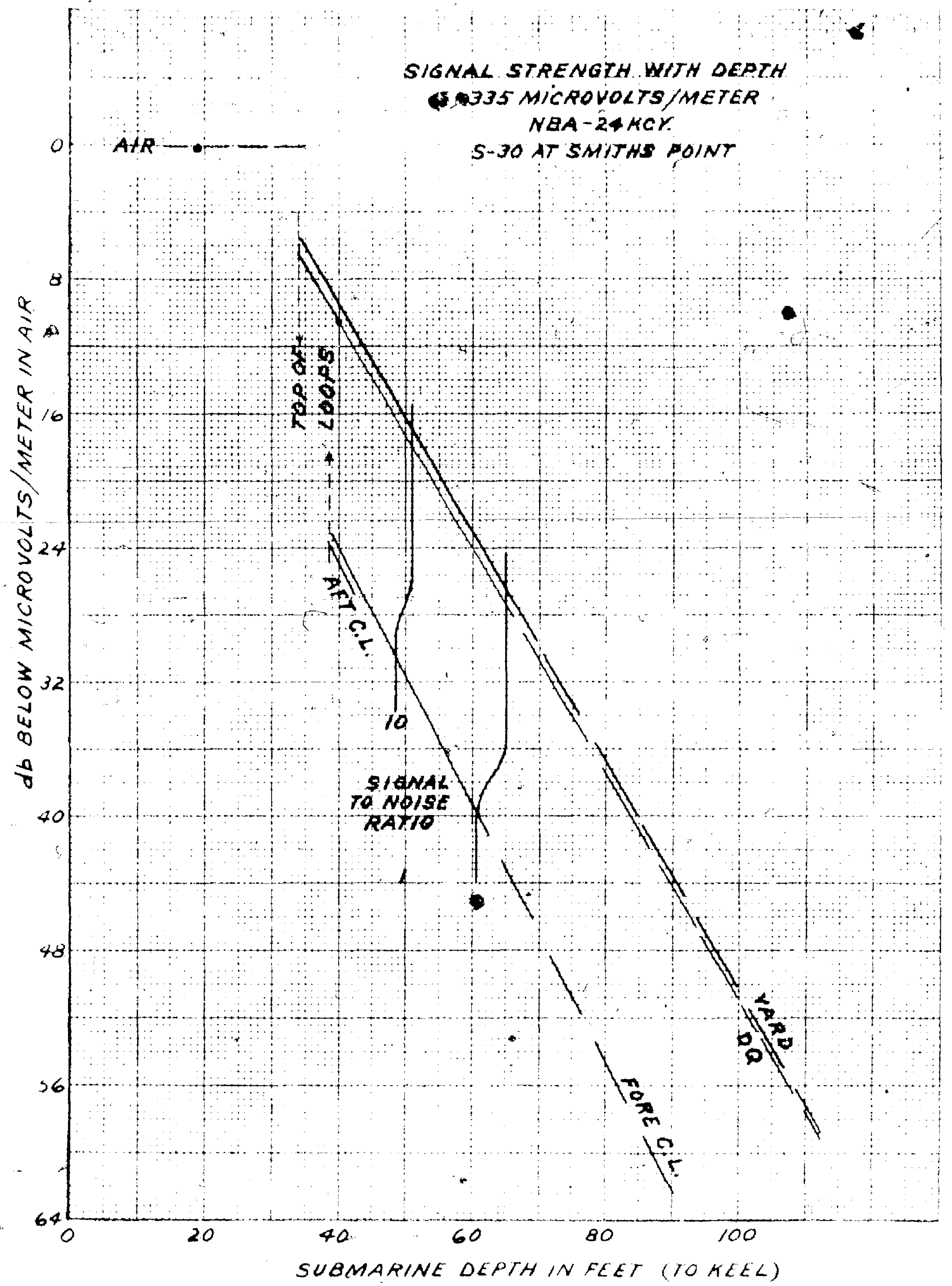
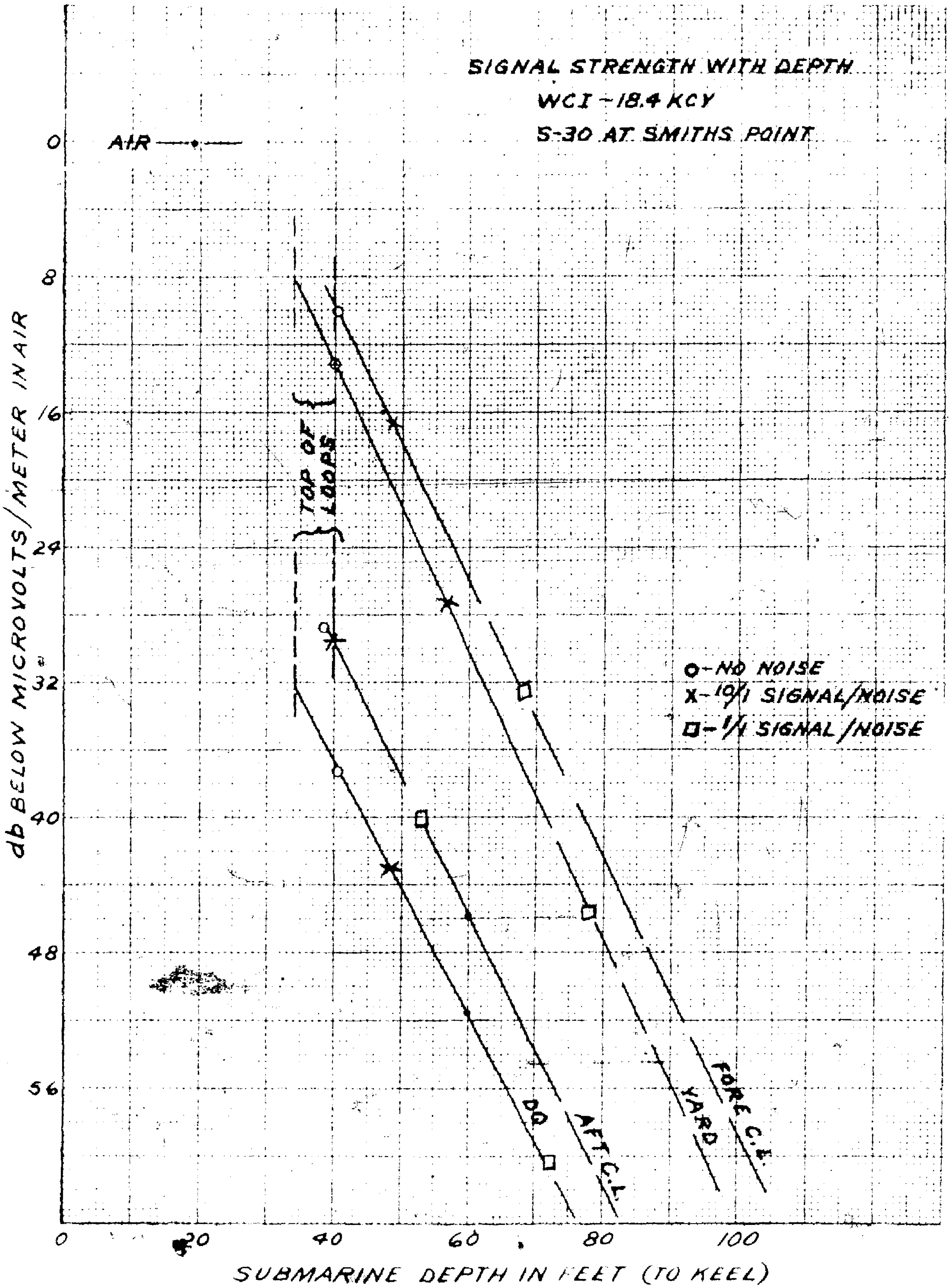

SIGNAL STRENGTH WITH DEPTH
NSS - 17.8 KCY
S-30 AT SMITHS POINT
AIR
TOP OF LOOPS
○- NO NOISE
X- 10/1 SIGNAL/NOISE
□- 1/1 SIGNAL/NOISE
YARD
FORE C.L.
AFT C.L.
DQ
db BELOW MICROVOLTS/METER IN AIR
0
8
16
24
32
40
48
56
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)

PLATE 8


SIGNAL STRENGTH WITH DEPTH
335 MICROVOLTS/METER
NBA-24 KCY.
S-30 AT SMITHS POINT
AIR
TOP OF LOOPS
10
SIGNAL TO NOISE RATIO
AFT C.L.
FORE C.L.
YARD
DQ
db BELOW MICROVOLTS/METER IN AIR
0
8
16
24
32
40
48
56
64
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)



SIGNAL STRENGTH WITH DEPTH
WCI - 18.4 KCY
S-30 AT SMITHS POINT
AIR
TOP OF LOOPS
O - NO NOISE
X - 10/1 SIGNAL/NOISE
□ - 1/1 SIGNAL/NOISE
DQ
AFT C.L.
YARD
FORE C.L.
db BELOW MICROVOLTS/METER IN AIR
0
8
16
24
32
40
48
56
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)

PLATE 10

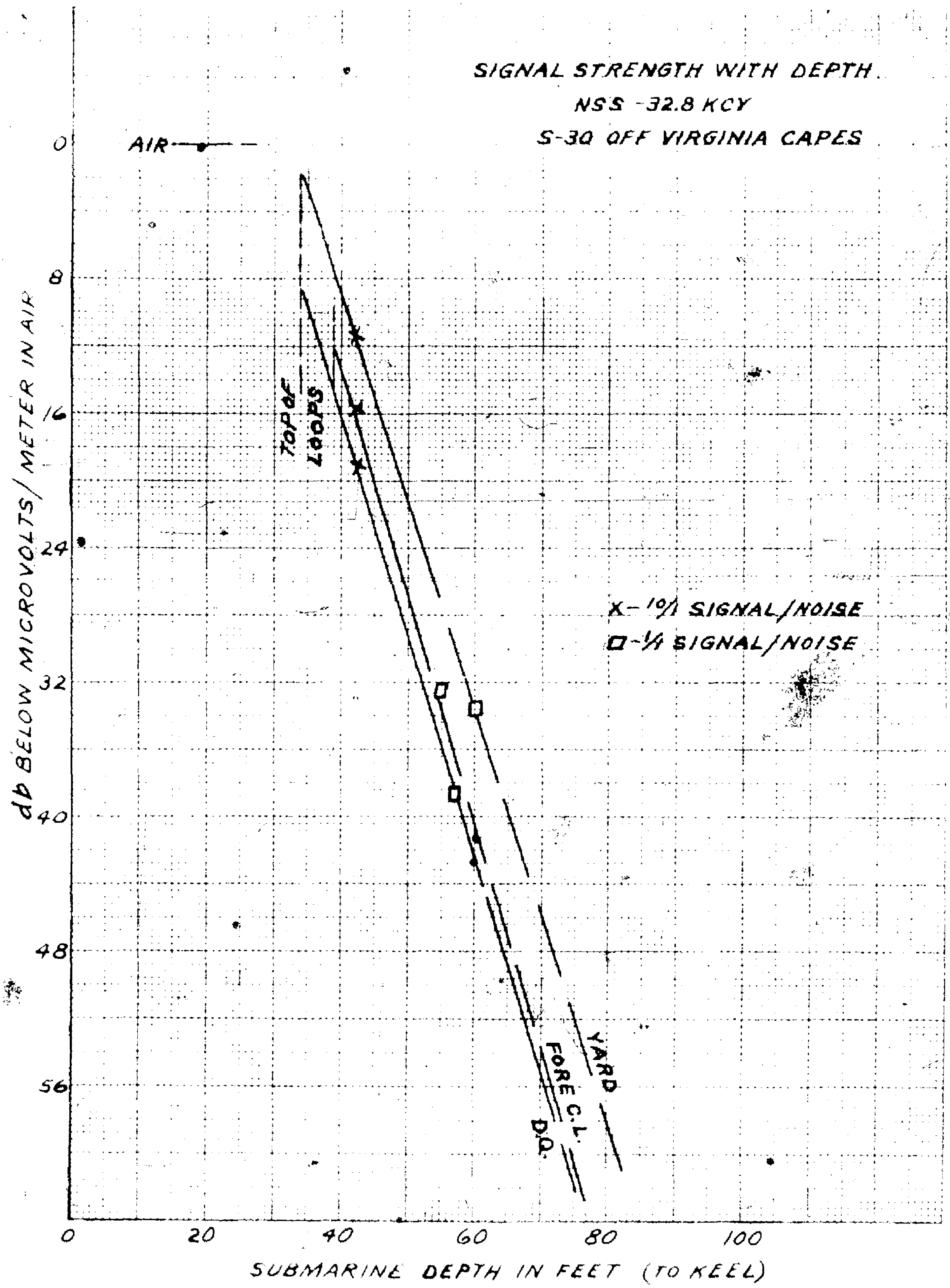
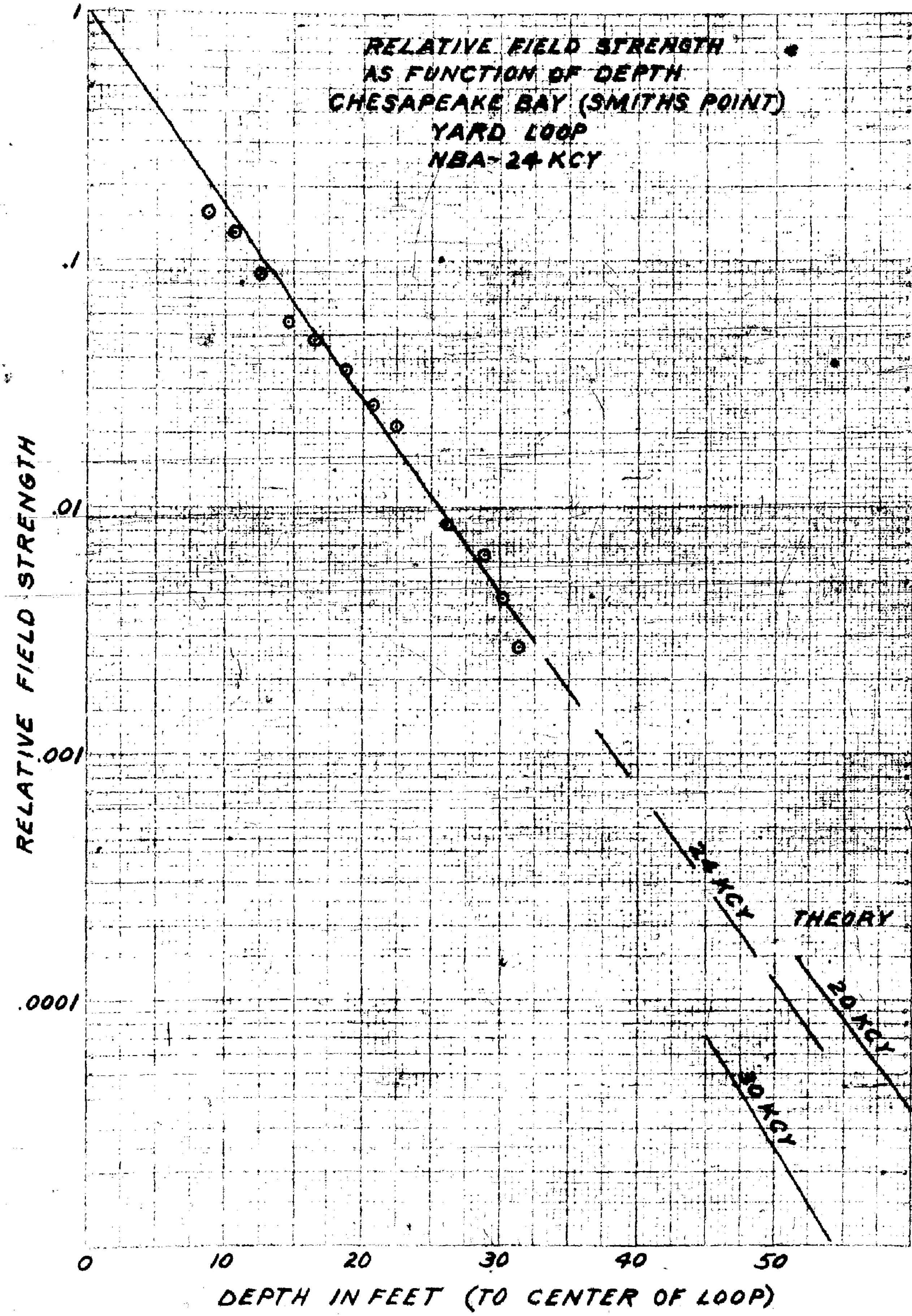
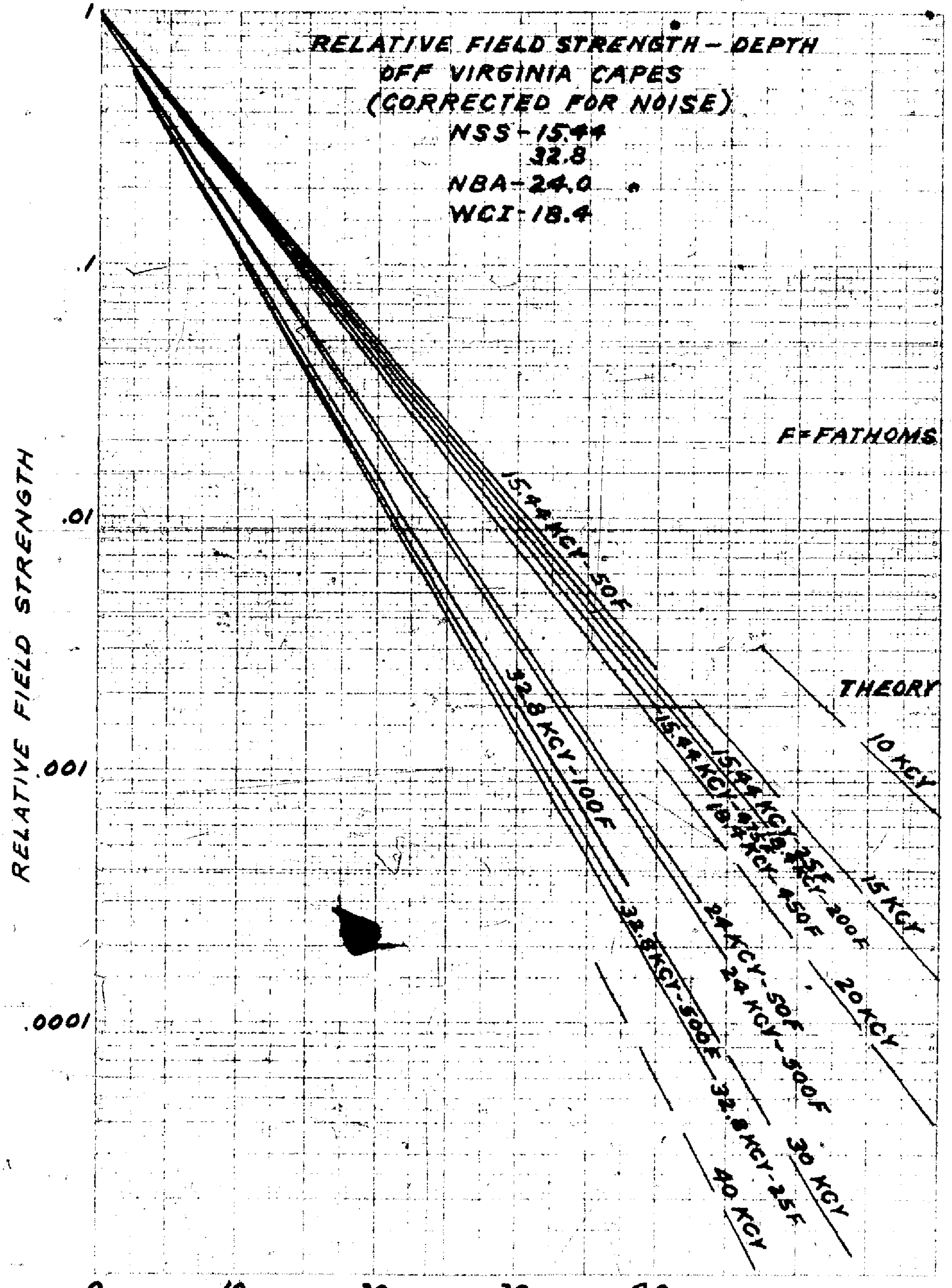

SIGNAL STRENGTH WITH DEPTH.
NSS -32.8 KCY
S-30 OFF VIRGINIA CAPES
AIR
TOP OF LOOPS
X- 1/1 SIGNAL/NOISE
□-1/1 SIGNAL/NOISE
YARD
FORE C.L.
D.Q.
db BELOW MICROVOLTS/METER IN AIR
0
8
16
24
32
40
48
56
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)

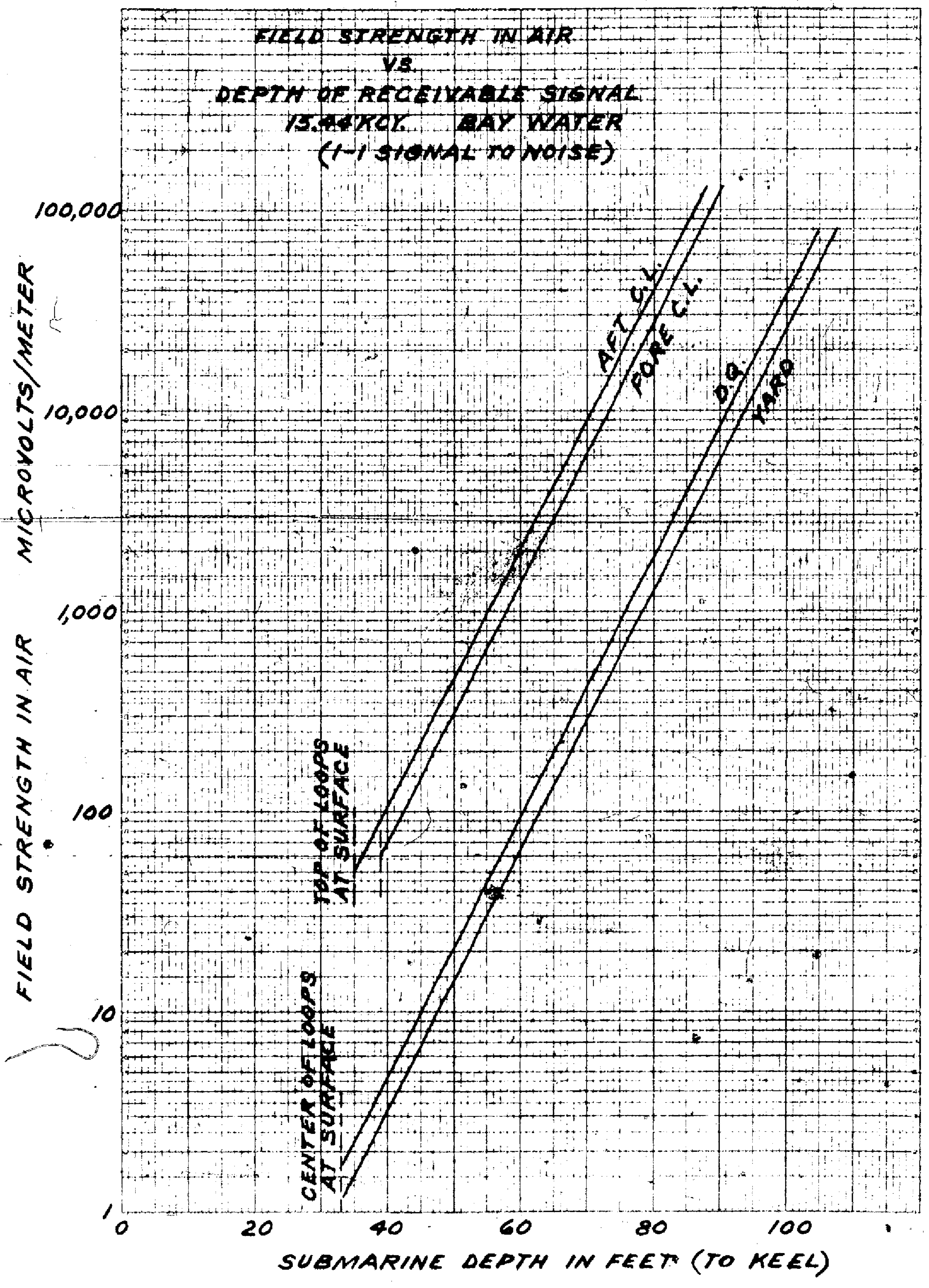
PLATE 11

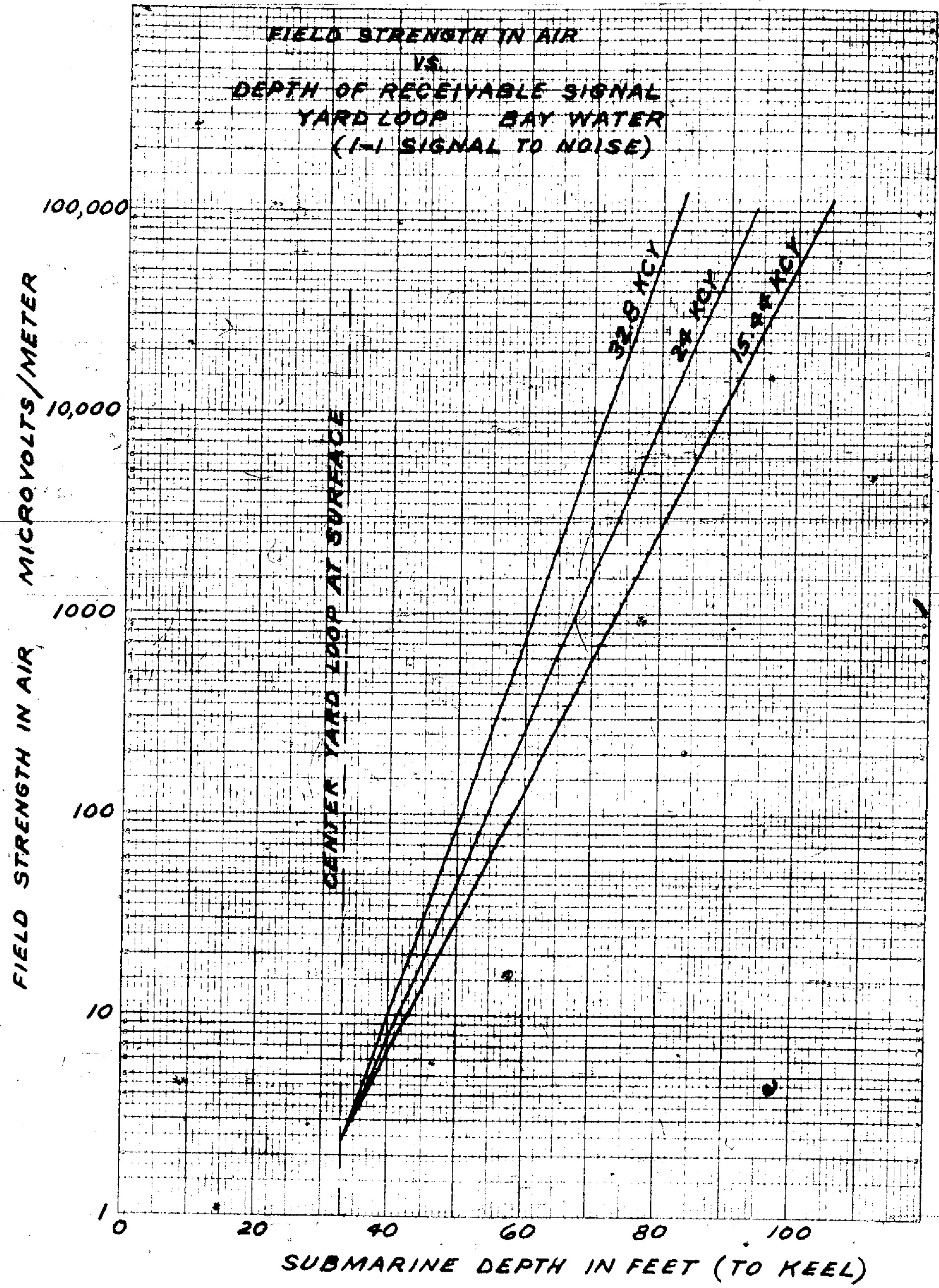


RELATIVE FIELD STRENGTH
AS FUNCTION OF DEPTH
CHESAPEAKE BAY (SMITHS POINT)
YARD LOOP
NBA - 24 KCY
RELATIVE FIELD STRENGTH
1
.1
.01
.001
.0001
0
10
20
30
40
50
DEPTH IN FEET (TO CENTER OF LOOP)
24 KCY
THEORY
20 KCY
30 KCY

PLATE 12


RELATIVE FIELD STRENGTH - DEPTH
OFF VIRGINIA CAPES
(CORRECTED FOR NOISE)
NSS - 15.44
32.8
NBA - 24.0
WCI - 18.4
F = FATHOMS
THEORY
10 KCY
15 KCY
20 KCY
30 KCY
40 KCY
15.44 KCY - 50F
32.8 KCY - 100F
32.8 KCY - 500F
32.8 KCY - 25F
24 KCY - 50F
24 KCY - 500F
RELATIVE FIELD STRENGTH
1
.1
.01
.001
.0001
0
10
20
30
40
LOOP DEPTH IN FEET (YARD)


FIELD STRENGTH IN AIR
VS
DEPTH OF RECEIVABLE SIGNAL
13.44 KCY. BAY WATER
(1-1 SIGNAL TO NOISE)
FIELD STRENGTH IN AIR MICROVOLTS/METER
100,000
10,000
1,000
100
10
1
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)
AFT C.L.
FORE C.L.
D.D.
YARD
TOP OF LOOPS AT SURFACE
CENTER OF LOOPS AT SURFACE



CODEX BOOK COMPANY, INC. NORWOOD, MASSACHUSETTS

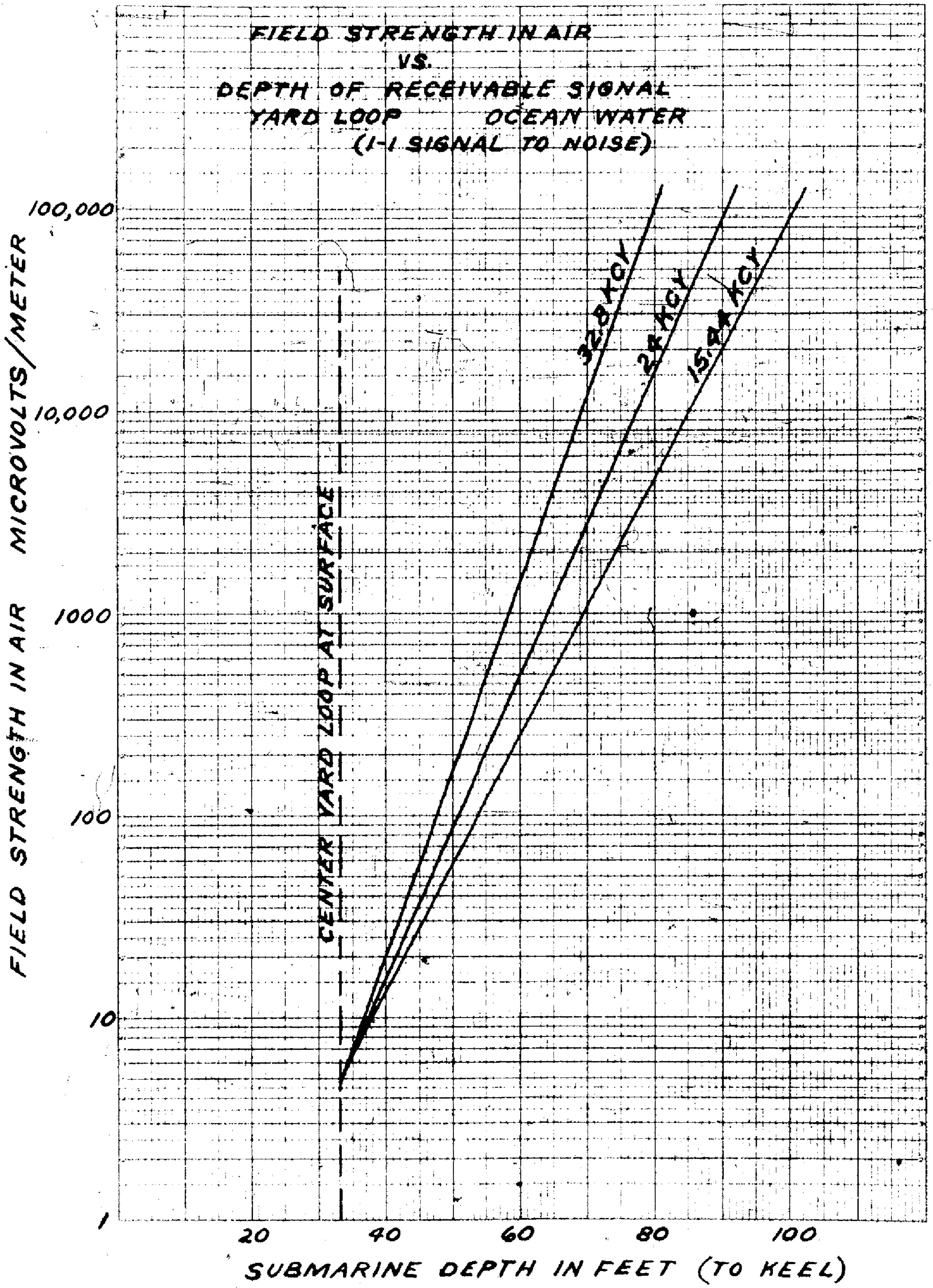
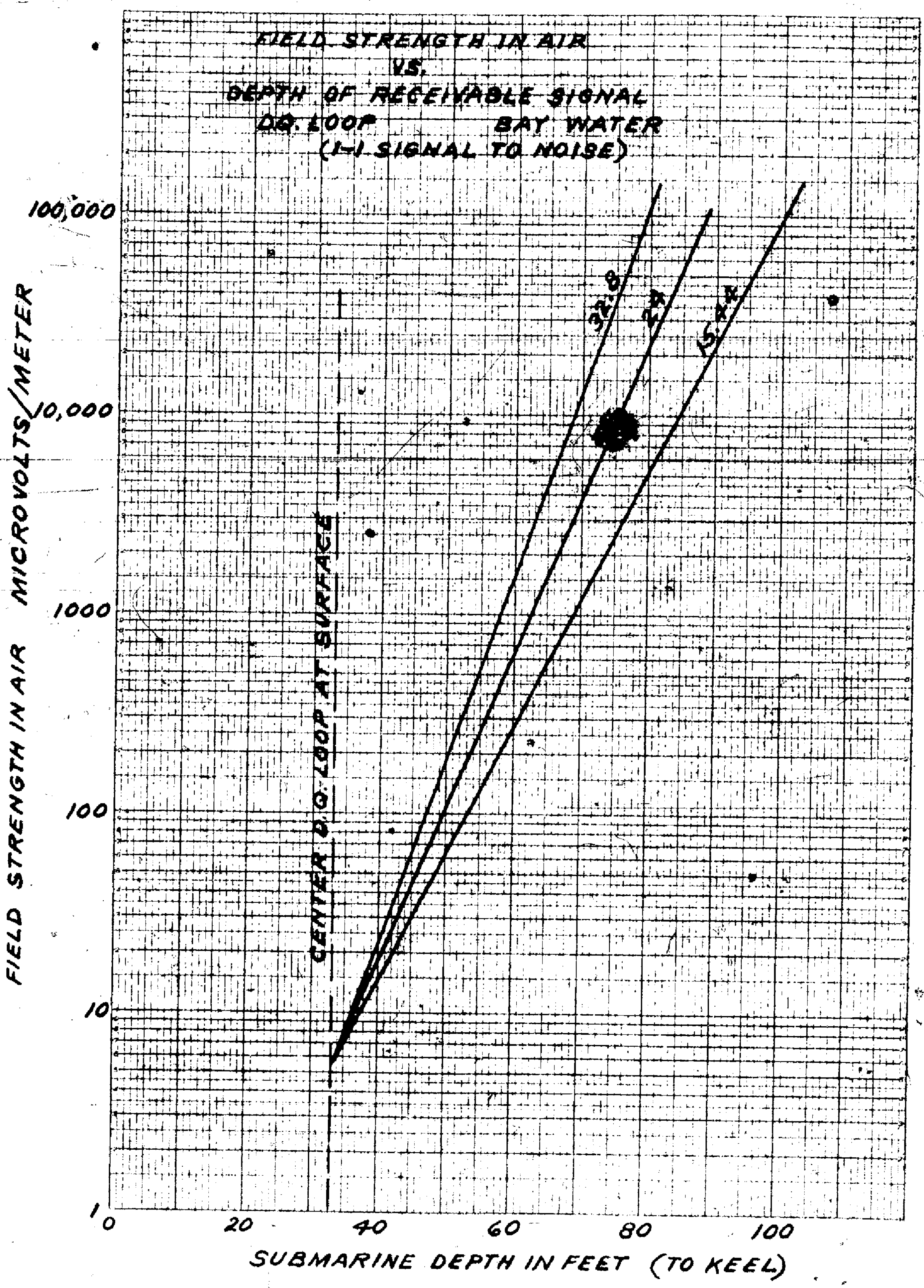
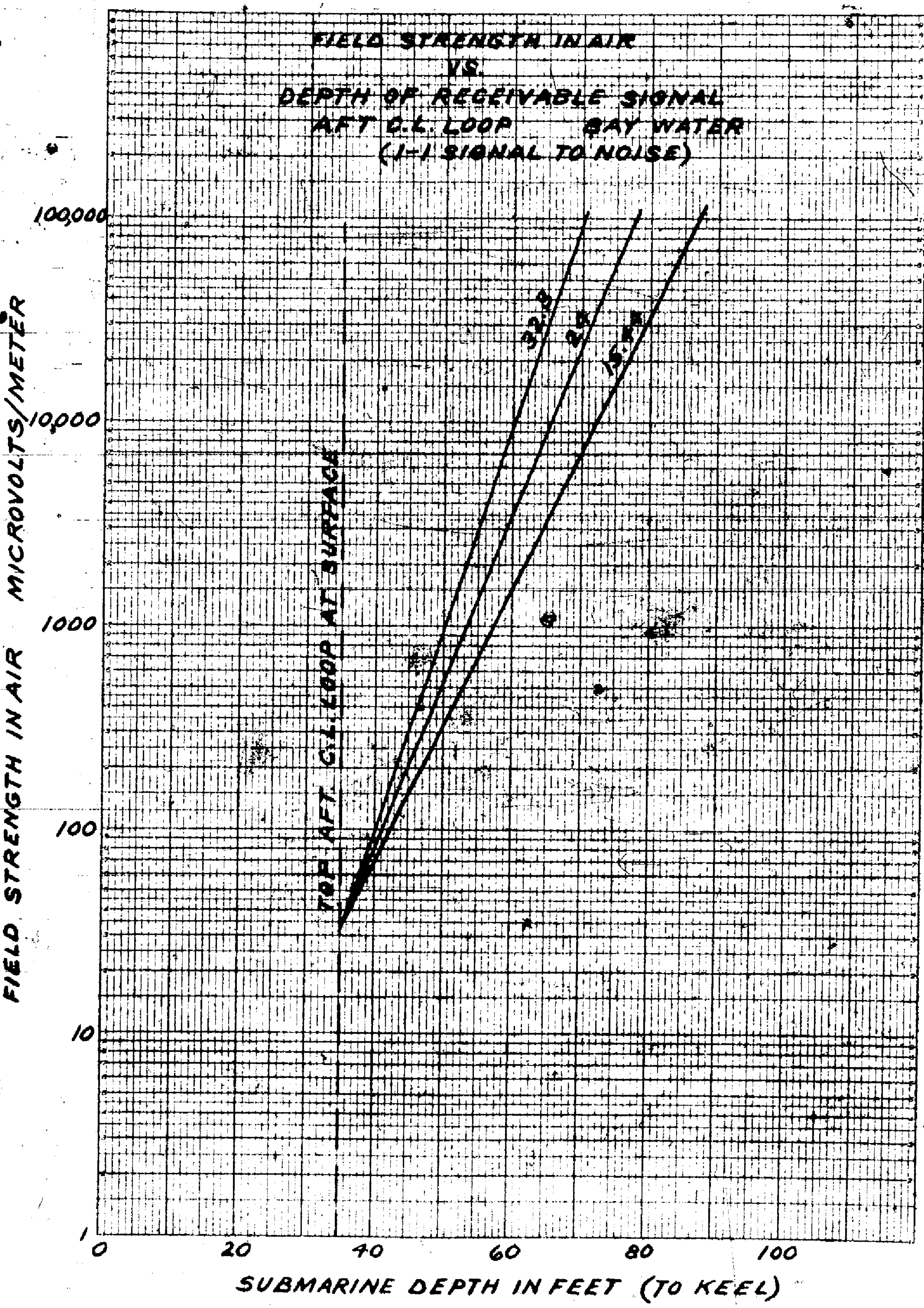

FIELD STRENGTH IN AIR
VS.
DEPTH OF RECEIVABLE SIGNAL
YARD LOOP OCEAN WATER
(1-1 SIGNAL TO NOISE)
FIELD STRENGTH IN AIR MICROVOLTS/METER
100,000
10,000
1000
100
10
1
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)
CENTER YARD LOOP AT SURFACE

PLATE 16



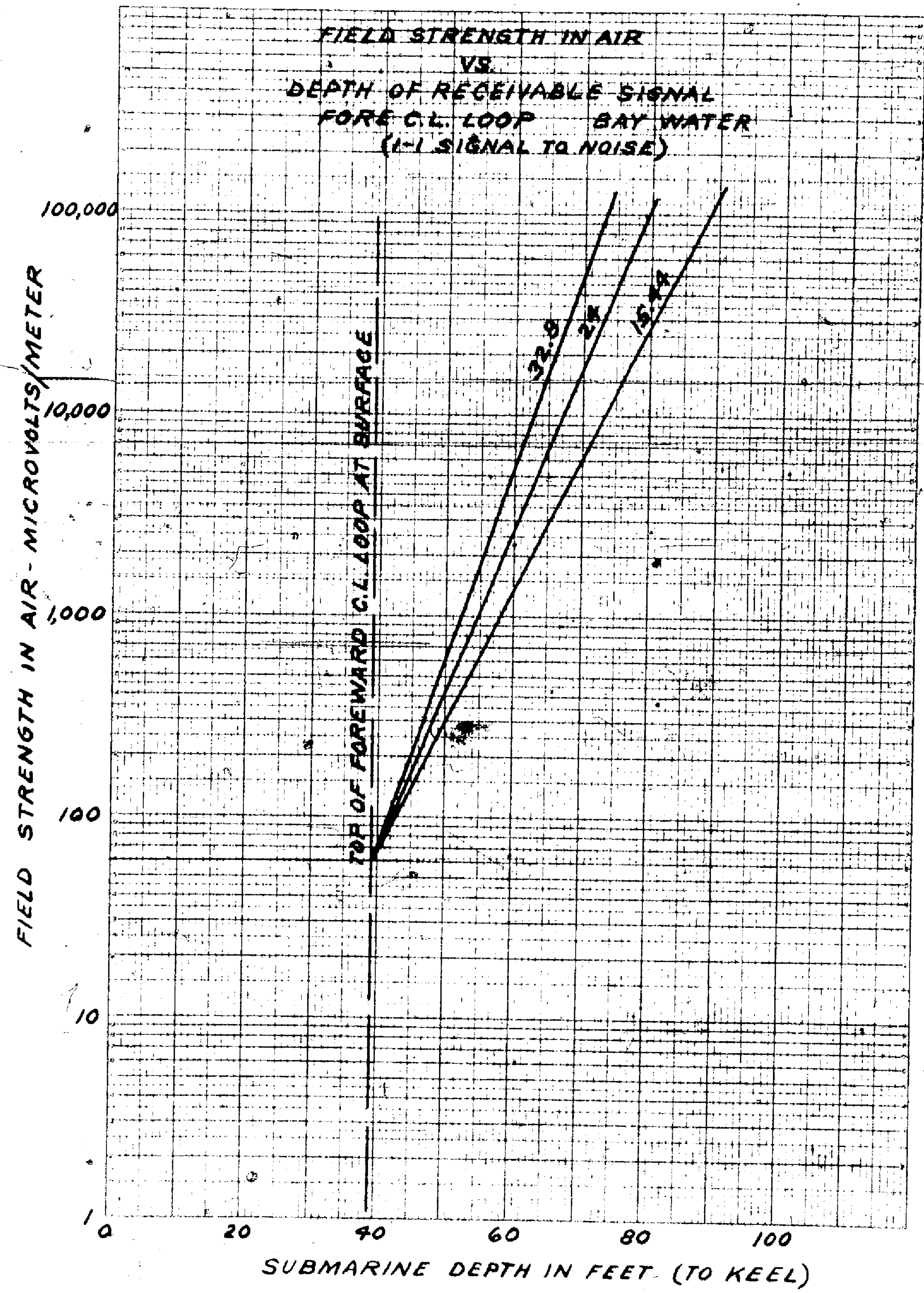
FIELD STRENGTH IN AIR
VS.
DEPTH OF RECEIVABLE SIGNAL
D.Q. LOOP BAY WATER
(1-1 SIGNAL TO NOISE)
FIELD STRENGTH IN AIR MICROVOLTS/METER
100,000
10,000
1000
100
10
1
32.8
24
15.8
CENTER D.Q. LOOP AT SURFACE
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)

PLATE 17



FIELD STRENGTH IN AIR
VS.
DEPTH OF RECEIVABLE SIGNAL
AFT C.L. LOOP BAY WATER
(1-1 SIGNAL TO NOISE)
TOP AFT C.L. LOOP AT SURFACE
FIELD STRENGTH IN AIR MICROVOLTS/METER
100,000
10,000
1000
100
10
1
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)

PLATE 18


FIELD STRENGTH IN AIR
VS
DEPTH OF RECEIVABLE SIGNAL
FORE C.L. LOOP BAY WATER
(1-1 SIGNAL TO NOISE)
FIELD STRENGTH IN AIR - MICROVOLTS/METER
100,000
10,000
1,000
100
10
1
0
20
40
60
80
100
SUBMARINE DEPTH IN FEET (TO KEEL)
TOP OF FOREWARD C.L. LOOP AT SURFACE
32.9
24
15.5

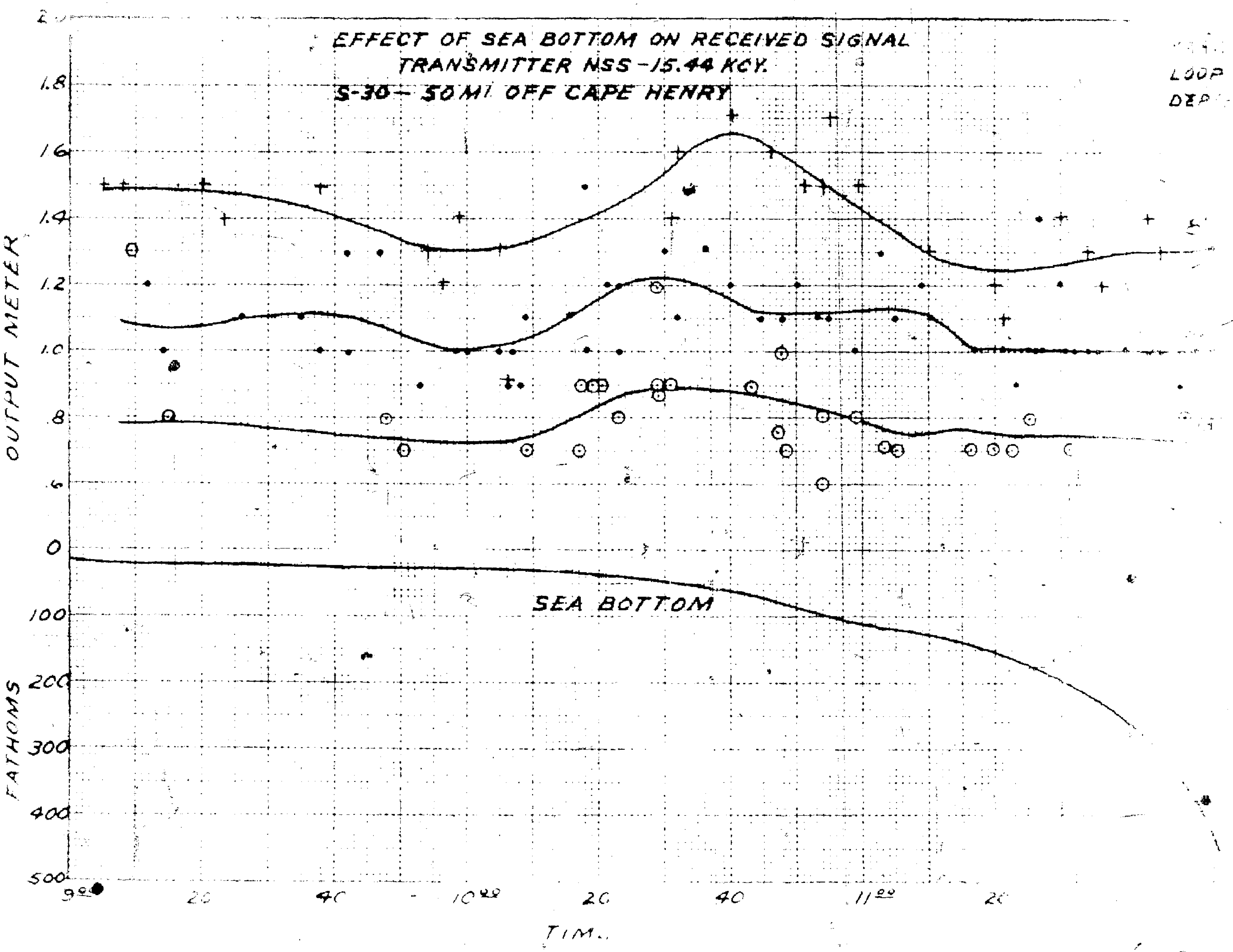

EFFECT OF SEA BOTTOM ON RECEIVED SIGNAL
TRANSMITTER NSS-15.44 KCY.
S-30 - 50 MI OFF CAPE HENRY
LOOP
DEP
OUTPUT METER
1.8
1.6
1.4
1.2
1.0
.8
.6
0
100
200
300
400
500
FATHOMS
SEA BOTTOM
40
20
TIM.

PLATE 2

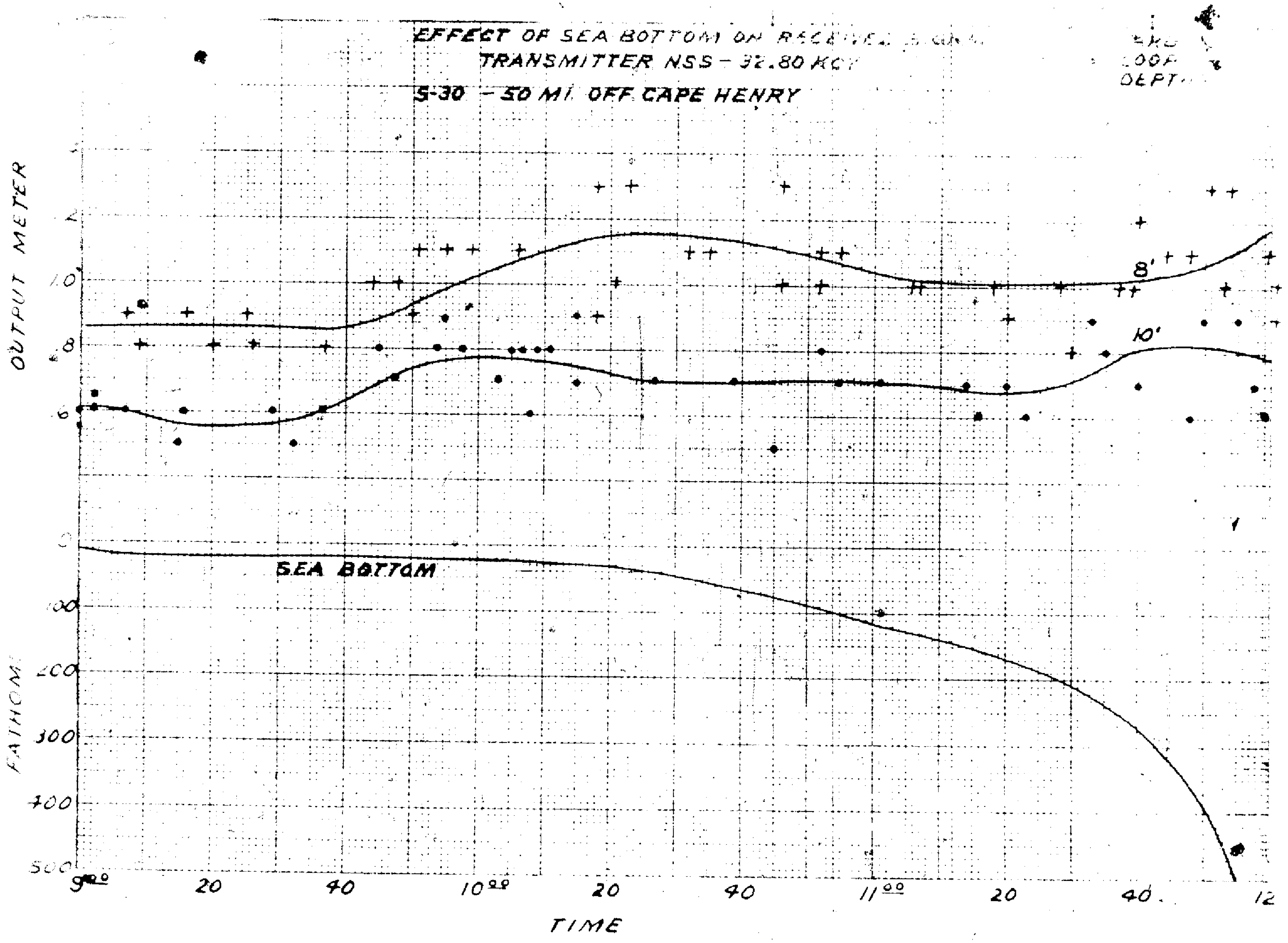

EFFECT OF SEA BOTTOM ON RECEIVED SIGNAL
TRANSMITTER NSS - 32.80 KCY
5-30 - 50 MI. OFF CAPE HENRY
OUTPUT METER
1.0
.8
.6
0
100
200
300
400
500
FATHOMS
8'
10'
SEA BOTTOM
9 00
20
40
10 00
20
40
11 00
20
40
12
TIME

PLATE 21

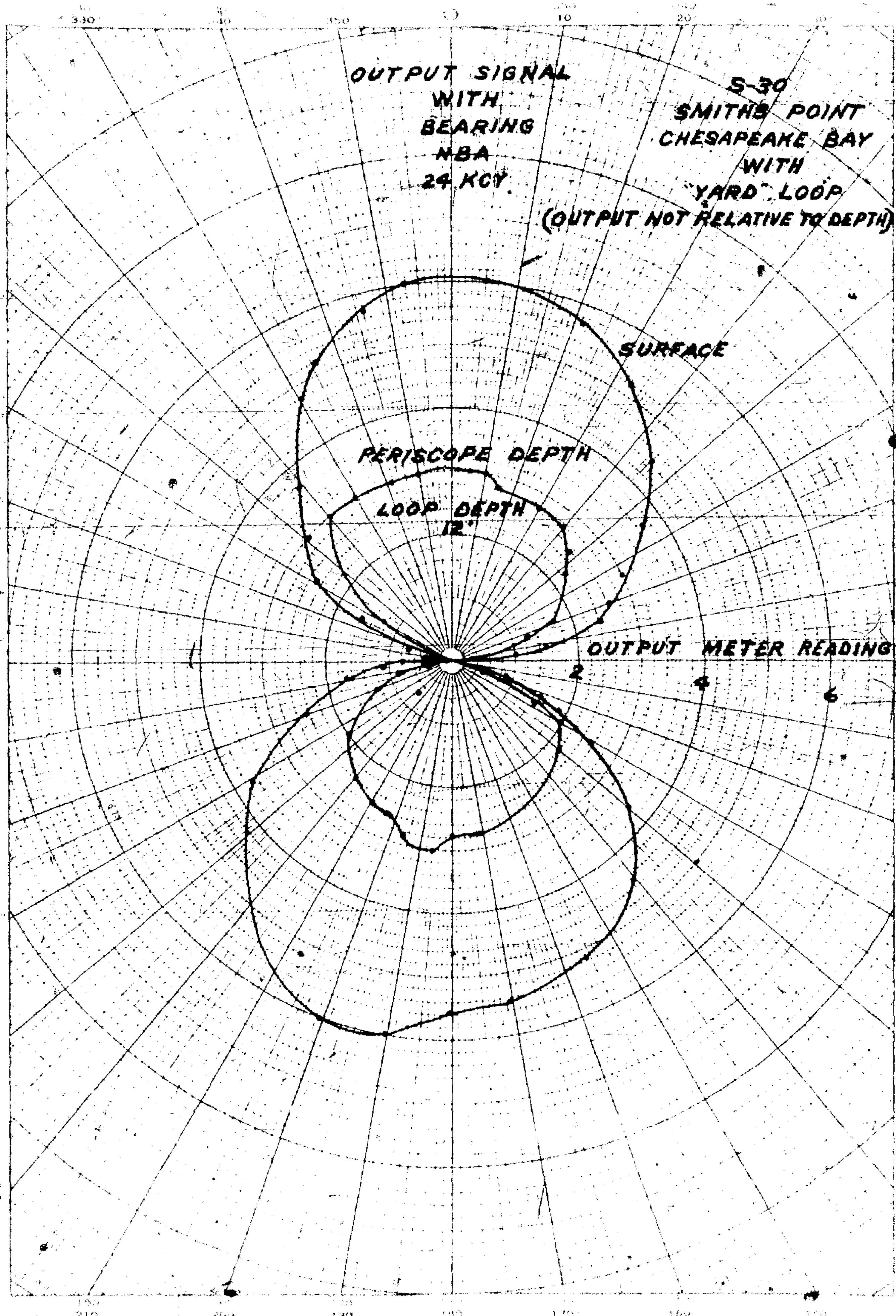

OUTPUT SIGNAL
WITH
BEARING
NBA
24 KCY.
S-30
SMITHS POINT
CHESAPEAKE BAY
WITH
"YARD" LOOP
(OUTPUT NOT RELATIVE TO DEPTH)
SURFACE
PERISCOPE DEPTH
LOOP DEPTH
12"
OUTPUT METER READING
2
4
6

PLATE 22

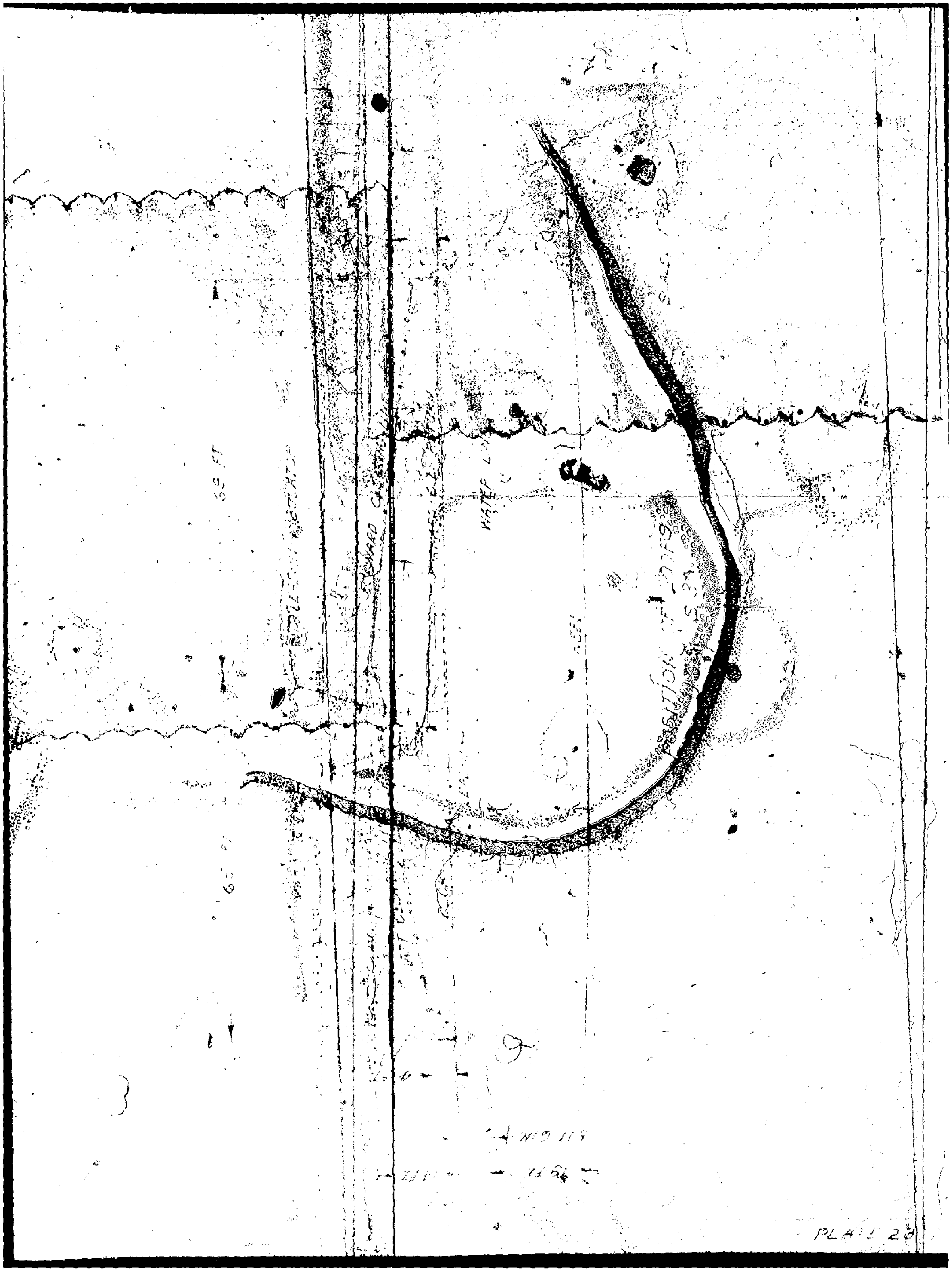
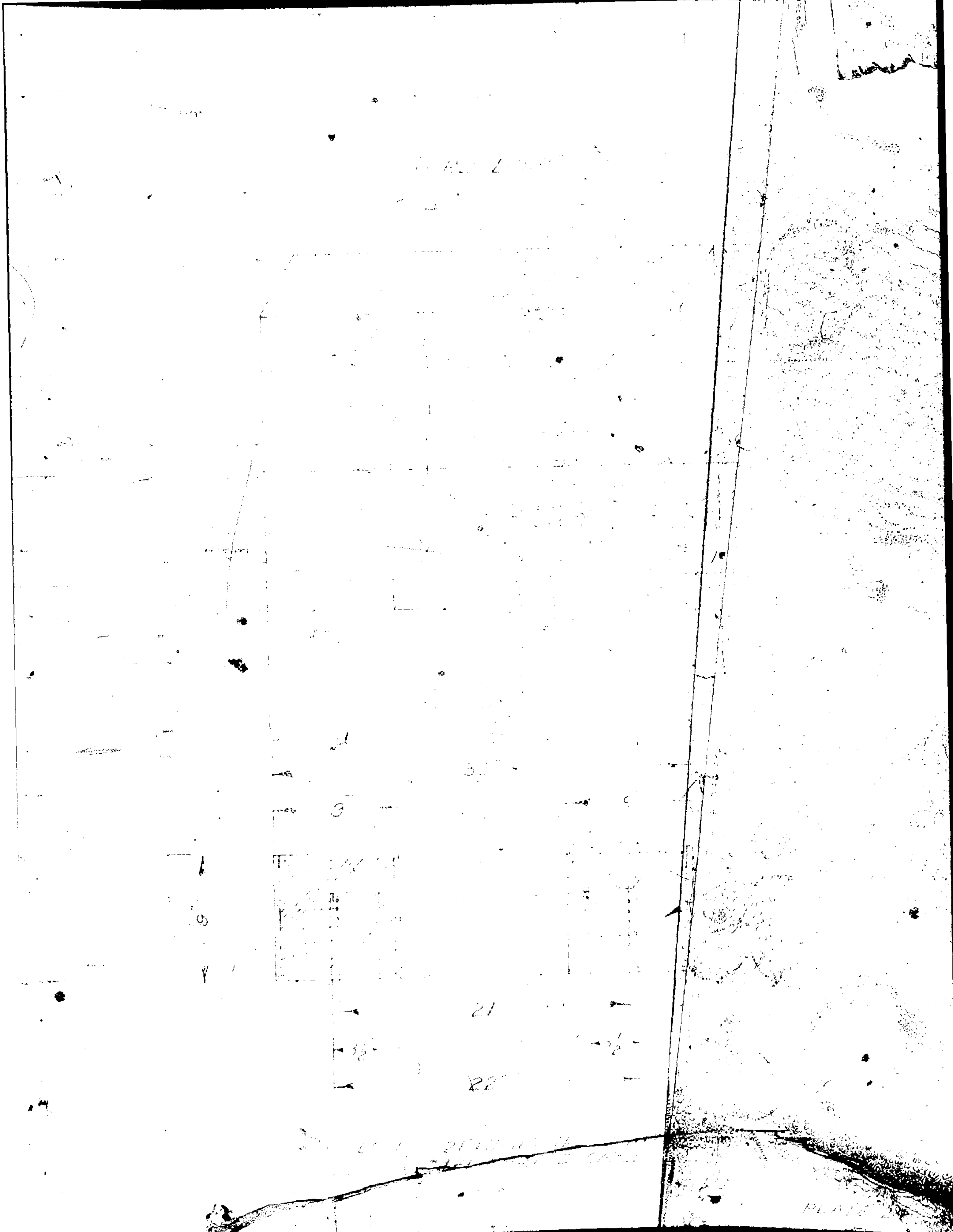
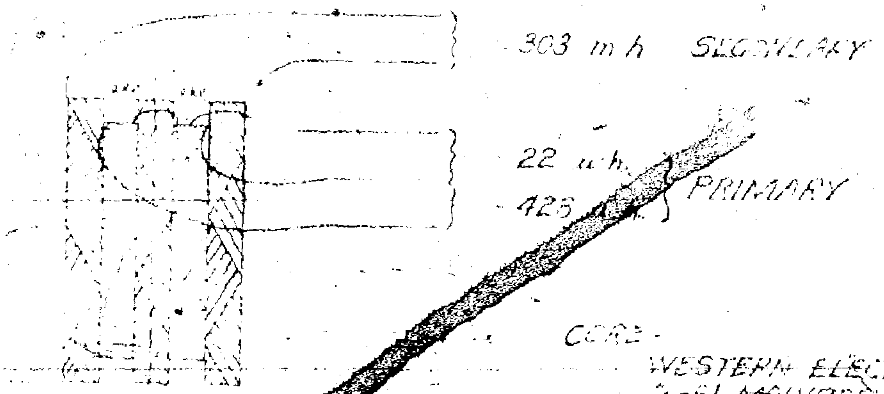


PLATE 28


3
21
22

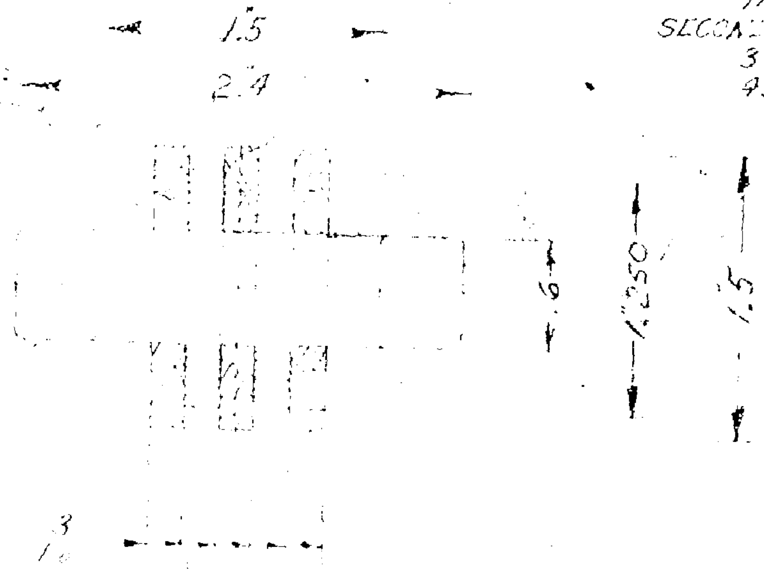
LOW COUPLING TRANSFORMER CONSTRUCTION



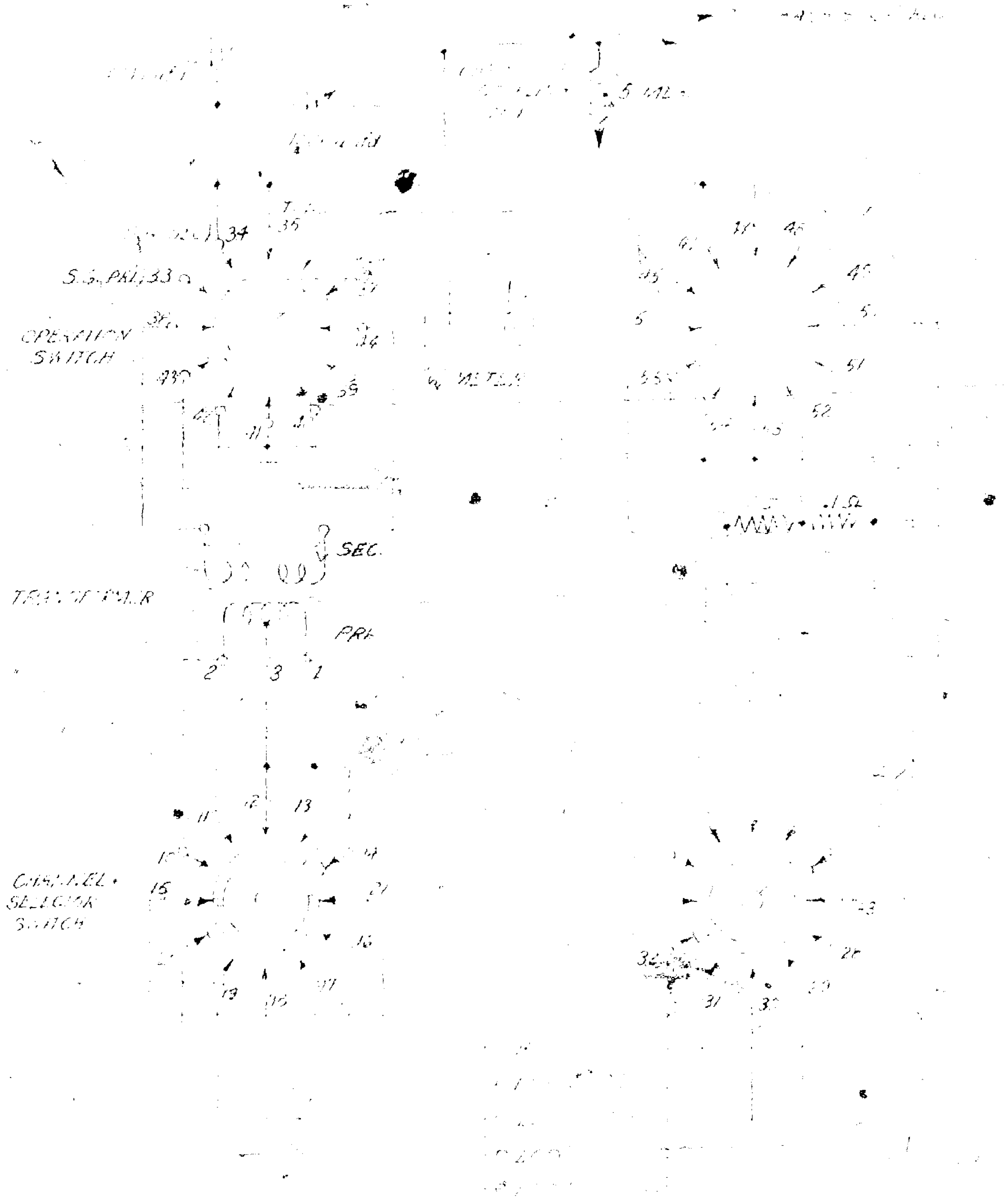
CORE -
WESTERN ELECTRIC
2-81 MOLYBDENUM PERMALLOY
2% MOLYBDENUM
81% NICKEL
17% IRON
APPARENT PERMEABILITY 26

PRIMARY -
2 PIES #12 ?
24 TURNS EACH
TAPPED AT 14

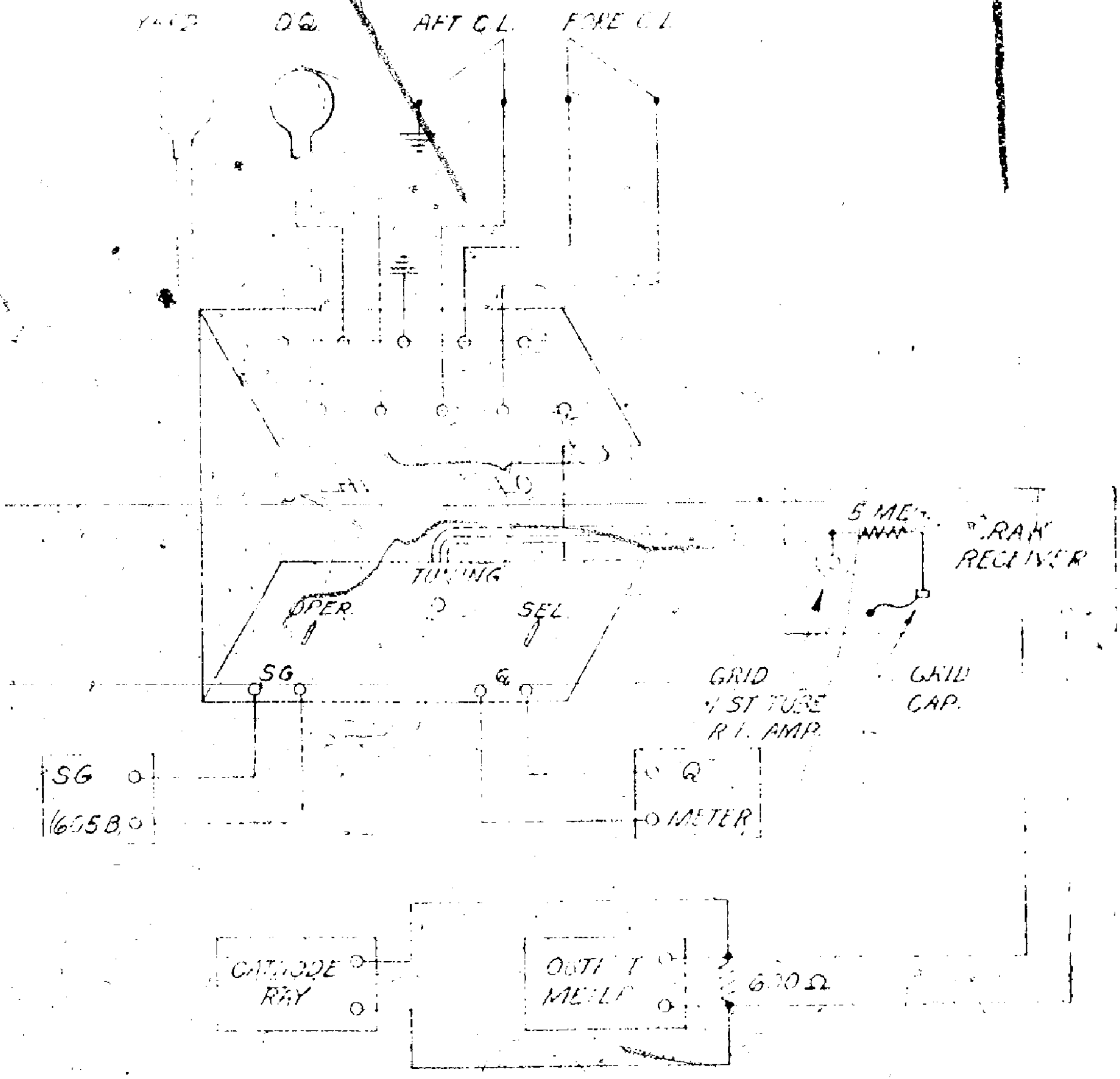
SECONDARY -
3 PIES # ?
450 TURNS EACH



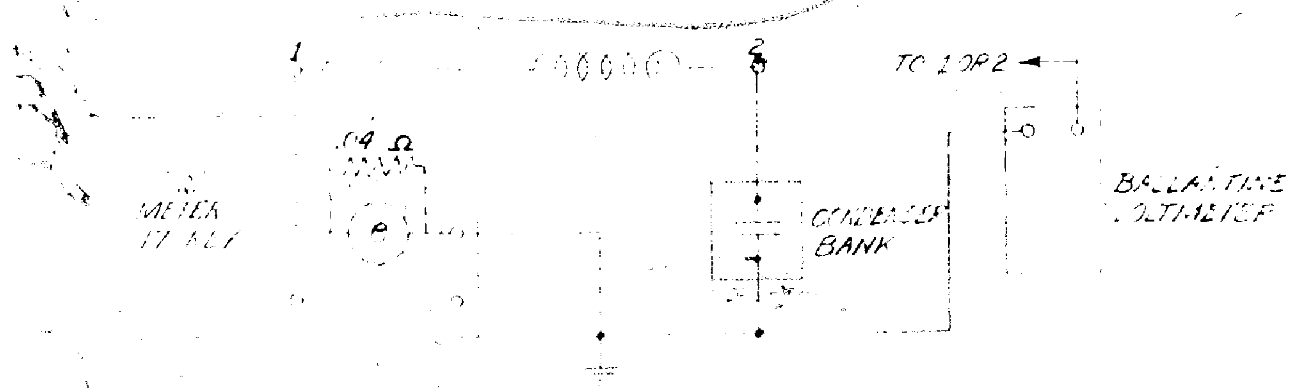
CIRCUIT DIAGRAM OF C[illegible] UNIT



BLOCK DIAGRAM OF CONNECTIONS.



MEASUREMENT OF LOOP Q



$$LOOP\ Q = \frac{E_2}{E_1}$$

CONSIDERATION ON THE DESIGN
OF UNDERWATER LOOPS

Assume: Inductance approximately same for equal areas

1^{v} signal/ft at top of loop

Frequency [illegible] Kcy.

From Plate 12 attenuation is [illegible]

Loop	Attenuation of signal at bottom	Voltage at bottom of loop	Net Voltage per foot	Net Voltage in loop
A	2.73 DB	[illegible]		.466
B	4.75 DB	.58	[illegible]	.42
C	1.58 DB	.835	[illegible]	.495

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DATE: 10 January, 2000

FROM: Mary Templeman, Code 5227

TO: ~~Dr. Shumaker, Code 5500~~ E. Kennedy, Code 5550

CC: Chuck Rogers, Code 1221.1 1/28/00

SUBJ: Review of NRL Report(s)

Dear Sir/Madam:

1. Please review **NRL-FR-3605, FR-1669 and FR-1717 for:**

- ☒ Possible Distribution Change
- ☐ Possible Change in Classification

Thank you,

Mary Templeman

Mary Templeman
(202)767-3425
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The subject report can be:

- ☒ Changed to Distribution A (Unlimited)
- ☐ Changed to Classification __________
- ☐ Other:

Edward J. Kennedy 1/21/00
Signature Date

UNCLASSIFIED

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